ACC/AHA 2008 Guidelines for the Management of Adults With Congenital Heart Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Develop Guidelines on the Management of Adults With Congenital Heart Disease) Developed in Collaboration With the American Society of Echocardiography, Heart Rhythm Society, International Society for Adult Congenital Heart Disease, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons

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PRACTICE GUIDELINE: FULL TEXT

ACC/AHA 2008 Guidelines for the Management of Adults With Congenital Heart Disease

A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Develop Guidelines on the Management of Adults With Congenital Heart Disease)

Developed in Collaboration With the American Society of Echocardiography, Heart Rhythm Society, International Society for Adult Congenital Heart Disease, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons

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This document was approved by the American College of Cardiology Foundation Board of Trustees in July 2008 and by the American Heart Association Science Advisory and Coordinating Committee in August 2008.

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Preamble

It is important that the medical profession play a central role in critically evaluating the use of diagnostic procedures and therapies introduced and tested for detection, management, or prevention of disease. Rigorous, expert analysis of the available data documenting absolute and relative benefits and risks of these procedures and therapies can produce guidelines that improve the effectiveness of care, optimize patient outcomes, and favorably affect the cost of care by focusing resources on the most effective strategies.

The American College of Cardiology Foundation (ACCF) and the American Heart Association (AHA) have jointly engaged in the production of guidelines in the area of cardiovascular disease since 1980. The American College of Cardiology (ACC)/AHA Task Force on Practice Guidelines is charged with developing, updating, and revising practice guidelines for cardiovascular diseases and procedures and directs this effort. Writing committees are charged with assessing the evidence as an independent group of authors to develop, update, or revise recommendations for clinical practice.

Experts in the subject under consideration have been selected from both organizations to examine subject-specific data and write guidelines in partnership with representatives from other medical practitioner and specialty groups. Writing committees are specifically charged to perform a formal literature review, weigh the strength of evidence for or against particular treatments or procedures, and include estimates of expected health outcomes where data exist. Patient-specific modifiers, comorbidities, and issues of patient preference that might influence the choice of tests or therapies are considered, as well as the frequency of follow-up and cost-effectiveness. When available, information from studies on cost is considered, but data on efficacy and clinical outcomes constitute the primary basis for recommendations in these guidelines.

The ACC/AHA Task Force on Practice Guidelines makes every effort to avoid actual, potential, or perceived conflicts of interest that might arise as a result of industry relationships or personal interests among the writing committee. Specifically, all members of the writing committee, as well as peer reviewers of the document, are asked to disclose all such relationships that might be perceived as real or potential conflicts of interest. Writing committee members are also strongly encouraged to declare previous relationships with industry that might be perceived as relevant to guideline development. If a writing committee member develops a new relationship with industry during their tenure, they are required to notify guideline staff in writing. These statements are reviewed by the parent task force, reported orally to all members at each meeting of the writing committee, and updated and reviewed by the writing committee as changes occur. Please refer to the methodology manual for ACC/AHA guideline writing committees for further description of the relationships with industry policy (1). See Appendix 1 for author relationships with industry and Appendix 2 for peer reviewer relationships with industry pertinent to this guideline.

These practice guidelines are intended to assist healthcare providers in clinical decision making by describing a range of generally acceptable approaches for diagnosis, management, and prevention of specific diseases or conditions. Clinicians should consider the quality and availability of expertise in the area where care is provided. These guidelines attempt to define practices that meet the needs of most patients in most circumstances. The recommendations reflect a consensus of expert opinion after a thorough review of the available current scientific evidence and are intended to improve patient care.

Patient adherence to prescribed and agreed upon medical regimens and lifestyles is an important aspect of treatment. Prescribed courses of treatment in accordance with these recommendations are only effective if they are followed. Because lack of patient understanding and adherence may adversely affect outcomes, physicians and other healthcare providers should make every effort to engage the patient's active participation in prescribed medical regimens and lifestyles.

If these guidelines are used as the basis for regulatory or payer decisions, the goal is quality of care and serving the patient's best interest. The ultimate judgment regarding care of a particular patient must be made by the healthcare provider and the patient in light of all of the circumstances presented by that patient. There are circumstances in which deviations from these guidelines are appropriate.

The guidelines will be reviewed annually by the ACC/AHA Task Force on Practice Guidelines and considered current unless they are updated, revised, or withdrawn from distribution. The executive summary and recommendations are published in the December 2, 2008, issue of the *Journal of the American College of Cardiology* and December 2, 2008, issue of *Circulation.* The full-text guidelines are e-published in the same issue of these journals and posted on the ACC (www.acc.org) and AHA (htttp://my.americanheart. org) World Wide Web sites.

Sidney C. Smith, Jr, MD, FACC, FAHA
Chair, ACC/AHA Task Force on Practice Guidelines

1. Introduction

1.1. Methodology and Evidence Review

The recommendations listed in this document are, whenever possible, evidence-based. Unlike other ACC/AHA practice guidelines, there is not a large body of peer-reviewed published evidence to support most recommendations, which will be clearly indicated in the text. An extensive literature survey was conducted that led to the incorporation of 647 references. Searches were limited to studies, reviews, and other evidence conducted in human subjects and published in English. Key search words included but were not limited to adult congenital heart disease (ACHD), atrial septal defect, arterial switch operation, bradycardia, cardiac catheterization, cardiac reoperation, coarctation, coronary artery abnormalities, cyanotic congenital heart disease, Doppler-echocardiography, d-transposition of the great arteries, Ebstein's anomaly, Eisenmenger physiology, familial, heart defect, medical therapy, patent ductus arteriosus, physical activity, pregnancy, psychosocial, pulmonary arterial hypertension, right heart

obstruction, supravalvular pulmonary stenosis, surgical therapy, tachyarrhythmia, tachycardia, tetralogy of Fallot, transplantation, tricuspid atresia, and Wolff-Parkinson-White. Additionally, the writing committee reviewed documents related to the subject matter previously published by the ACC and AHA. References selected and published in this document are representative and not all-inclusive.

The committee reviewed and ranked evidence supporting current recommendations with the weight of evidence ranked as Level A if the data were derived from multiple randomized clinical trials involving a large number of individuals. The committee ranked available evidence as Level B when data were derived from a limited number of trials involving a comparatively small number of patients or from well-designed data analyses of nonrandomized studies or observational data registries. Evidence was ranked as Level C when the consensus of experts was the primary source of the recommendation. In the narrative portions of these guidelines, evidence is generally presented in chronological order of development. Studies are identified as observational, randomized, prospective, or retrospective. The committee emphasizes that for certain conditions for which no other therapy is available, the indications are based on expert consensus and years of clinical experience and are thus well supported, even though the evidence was ranked as Level C. An analogous example is the use of penicillin in pneumococcal pneumonia where there are no randomized trials and only clinical experience. When indications at Level C are supported by historical clinical data, appropriate references (eg, case reports and clinical reviews) are cited if available. When Level C indications are based strictly on committee consensus, no references are cited. The final recommendations for indications for a diagnostic procedure, a particular therapy, or an intervention in ACHD patients summarize both clinical evidence and expert opinion. The schema for classification of recommendations and level of evidence is summarized in Table 1, which also illustrates how the grading system provides an estimate of the size of treatment effect and an estimate of the certainty of the treatment effect.

1.2. Organization of Committee and Relationships With Industry

The ACC/AHA Task Force on Practice Guidelines was formed to create clinical practice guidelines for select cardiovascular conditions with important implications for public health. This guideline writing committee was assembled to adjudicate the evidence and construct recommendations regarding the diagnosis and treatment of ACHD. Writing committee members were selected with attention to ACHD subspecialties, broad geographic representation, and involvement in academic medicine and clinical practice. The writing committee included representatives of the American Society of Echocardiography, Heart Rhythm Society, International Society for Adult Congenital Heart Disease, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons.

All members of the writing committee were required to disclose all relationships with industry relevant to the data under consideration (1).

1.3. Document Review and Approval

This document was reviewed by 3 external reviewers nominated from both the ACC and the AHA, as well as reviewers from the American Society of Echocardiography, Canadian Cardiovascular Society, Heart Rhythm Society, International Society for Adult Congenital Heart Disease, and Society of Thoracic Surgeons, and 20 individual content reviewers which included reviewers from the ACC Congenital Heart Disease and Pediatric Cardiology Committee and the AHA Congenital Cardiac Defects Committee. All reviewer relationships with industry information were collected and distributed to the writing committee and are published in this document (see Appendix 2 for details).

This document was approved for publication by the governing bodies of the ACCF and the AHA and endorsed by the American Society of Echocardiography, Heart Rhythm Society, International Society for Adult Congenital Heart Disease, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons.

1.4. Epidemiology and Scope of the Problem

Remarkable improvement in survival of patients with congenital heart disease (CHD) has occurred over the past half century since reparative surgery has become commonplace. Since the advent of neonatal repair of complex lesions in the 1970s, an estimated 85% of patients survive into adult life. The 32nd Bethesda Conference report in 2000 estimated that there were approximately 800 000 adults with CHD in the United States (2,3). Given modern surgical mortality rates of less than 5%, one would expect that in the next decade, almost 1 in 150 young adults will have some form of CHD. In particular, there are a substantial number of young adults with single-ventricle physiology, systemic right ventricles (RVs), or complex intracardiac baffles who are now entering adult life and starting families. Young adults have many psychological, social, and financial issues that present barriers to proactive health management. The infrastructure that is provided to most pediatric cardiology centers, namely, case management by advanced practice nurses and social workers, is largely lacking within the adult healthcare system. Recognizing the compound effects of a complex and unfamiliar disease with an unprepared patient and healthcare system, the ACC/AHA ACHD Guideline Writing Committee has determined that the most immediate step it can take to support the practicing cardiologist in the care of ACHD patients is to provide a consensus document that outlines the most important diagnostic and management strategies and indicates when referral to a highly specialized center is appropriate. To provide ease of use, the writing committee constructed this document by lesion type and in each section included recommendations on topics common to all lesions (eg, infective endocarditis [IE] prophylaxis, pregnancy, physical activity, and medical therapy).

1.5. Recommendations for Delivery of Care and Ensuring Access

CLASS I

1. The focus of current healthcare access goals for ACHD patients should include the following:

Table 1. Applying Classification of Recommendations and Level of Evidence

ESTIMATE OF CERTAINTY (PRECISION) OF TREATMENT EFFECT	SIZE OF TREATMENT EFFECT →			
	CLASS I *Benefit >>> Risk* Procedure/Treatment **SHOULD** be performed/administered	**CLASS IIa** *Benefit >> Risk* *Additional studies with focused objectives needed* **IT IS REASONABLE** to perform procedure/administer treatment	**CLASS IIb** *Benefit ≥ Risk* *Additional studies with broad objectives needed; additional registry data would be helpful* Procedure/Treatment **MAY BE CONSIDERED**	**CLASS III** *Risk ≥ Benefit* Procedure/Treatment should **NOT** be performed/administered **SINCE IT IS NOT HELPFUL AND MAY BE HARMFUL**
LEVEL A Multiple populations evaluated* Data derived from multiple randomized clinical trials or meta-analyses	■ Recommendation that procedure or treatment is useful/effective ■ Sufficient evidence from multiple randomized trials or meta-analyses	■ Recommendation in favor of treatment or procedure being useful/effective ■ Some conflicting evidence from multiple randomized trials or meta-analyses	■ Recommendation's usefulness/efficacy less well established ■ Greater conflicting evidence from multiple randomized trials or meta-analyses	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Sufficient evidence from multiple randomized trials or meta-analyses
LEVEL B Limited populations evaluated* Data derived from a single randomized trial or nonrandomized studies	■ Recommendation that procedure or treatment is useful/effective ■ Evidence from single randomized trial or nonrandomized studies	■ Recommendation in favor of treatment or procedure being useful/effective ■ Some conflicting evidence from single randomized trial or nonrandomized studies	■ Recommendation's usefulness/efficacy less well established ■ Greater conflicting evidence from single randomized trial or nonrandomized studies	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Evidence from single randomized trial or nonrandomized studies
LEVEL C Very limited populations evaluated* Only consensus opinion of experts, case studies, or standard of care	■ Recommendation that procedure or treatment is useful/effective ■ Only expert opinion, case studies, or standard of care	■ Recommendation in favor of treatment or procedure being useful/effective ■ Only diverging expert opinion, case studies, or standard of care	■ Recommendation's usefulness/efficacy less well established ■ Only diverging expert opinion, case studies, or standard of care	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Only expert opinion, case studies, or standard of care
Suggested phrases for writing recommendations†	should is recommended is indicated is useful/effective/beneficial	is reasonable can be useful/effective/beneficial is probably recommended or indicated	may/might be considered may/might be reasonable usefulness/effectiveness is unknown/unclear/uncertain or not well established	is not recommended is not indicated should not is not useful/effective/beneficial may be harmful

*Data available from clinical trials or registries about the usefulness/efficacy in different subpopulations, such as gender, age, history of diabetes, history of prior myocardial infarction, history of heart failure, and prior aspirin use. A recommendation with Level of Evidence B or C does not imply that the recommendation is weak. Many important clinical questions addressed in the guidelines do not lend themselves to clinical trials. Even though randomized trials are not available, there may be a very clear clinical consensus that a particular test or therapy is useful or effective.

†In 2003, the ACC/AHA Task Force on Practice Guidelines developed a list of suggested phrases to use when writing recommendations. All guideline recommendations have been written in full sentences that express a complete thought, such that a recommendation, even if separated and presented apart from the rest of the document (including headings above sets of recommendations), would still convey the full intent of the recommendation. It is hoped that this will increase readers' comprehension of the guidelines and will allow queries at the individual recommendation level.

a. Strengthening organization of and access to transition clinics for adolescents and young adults with CHD, including funding of allied healthcare providers to provide infrastructure comparable to that provided for children with CHD. (*Level of Evidence: C*)

b. Organization of outreach and education programs for patients, their families, and caregivers to recapture patients leaving pediatric supervisory care or who are lost to follow-up. Such programs can determine when and where further intervention is required. (*Level of Evidence: C*)

c. Enhanced education of adult cardiovascular specialists and pediatric cardiologists in the pathophysiology and management of ACHD patients. (*Level of Evidence: C*)

d. A liaison with regulatory agencies at the local, regional, state, and federal levels to create programs commensurate with the needs of this large cardiovascular population. (*Level of Evidence: C*)

2. Health care for ACHD patients should be coordinated by regional ACHD centers of excellence that would serve as a resource for the surrounding medical community, affected individuals, and their families (Table 2).

a. Every academic adult cardiology/cardiac surgery center should have access to a regional ACHD center for consultation and referral. (*Level of Evidence: C*)

b. Each pediatric cardiology program should identify the ACHD center to which the transfer of patients can be made. (*Level of Evidence: C*)

c. All emergency care facilities should have an affiliation with a regional ACHD center. (*Level of Evidence: C*)

Table 2. Personnel and Services Recommended for Regional ACHD Centers

Type of Service	Personnel/Resources
Cardiologist specializing in ACHD	One or several 24/7
Congenital cardiac surgeon	Two or several 24/7
Nurse/physician assistant/nurse practitioner	One or several
Cardiac anesthesiologist	Several 24/7
Echocardiography*	Two or several 24/7
• Includes TEE, intraoperative TEE	
Diagnostic catheterization*	Yes, 24/7
Noncoronary interventional catheterization*	Yes, 24/7
Electrophysiology/pacing/AICD implantation*	One or several
Exercise testing	• Echocardiography
	• Radionuclide
	• Cardiopulmonary
	• Metabolic
Cardiac imaging/radiology*	• Cardiac MRI
	• CT scanning
	• Nuclear medicine
Multidisciplinary teams	• High-risk obstetrics
	• Pulmonary hypertension
	• Heart failure/transplant
	• Genetics
	• Neurology
	• Nephrology
	• Cardiac pathology
	• Rehabilitation services
	• Social services
	• Vocational services
	• Financial counselors
Information technology	• Data collection
	• Database support
	• Quality assessment review/protocols

*These modalities must be supervised/performed and interpreted by physicians with expertise and training in congenital heart disease.

ACHD indicates adult congenital heart disease; 24/7, availability 24 hours per day, 7 days per week; TEE, transesophageal echocardiography; AICD, automatic implantable cardioverter defibrillator; MRI, magnetic resonance imaging; and CT, computed tomography.

3. **ACHD patients should carry a complete medical "passport" that outlines specifics of their past and current medical history, as well as contact information for immediate access to data and counsel from local and regional centers of excellence. (*Level of Evidence: C*)**
4. **Care of some ACHD patients is complicated by additional special needs, including but not restricted to intellectual incapacities or psychosocial limitations that necessitate the inclusion of designated healthcare guardians in all medical decision making. (*Level of Evidence: C*)**
5. **Every ACHD patient should have a primary care physician. To ensure and improve communication, current clinical records should be on file with the primary care physician and a local cardiovascular specialist, as well as at a regional ACHD center; patients should also have copies of relevant records. (*Level of Evidence: C*)**
6. **Every cardiovascular family caregiver should have a referral relationship with a regional ACHD center so that all patients have geographically accessible care. (*Level of Evidence: C*)**

The need for delivery of appropriate healthcare to ACHD patients largely remains unmet. The 32nd Bethesda Conference report in 2000 recommended organizing ACHD care within a regional and national system of specialized adult CHD centers of excellence that would disseminate care, provide education, orchestrate research and innovation, and serve as a general resource for the region within this model (3) (Table 2). Such a system has been demonstrated to improve care for adults with similar chronic severe illness, such as severe heart failure, for which measures of improvement surrounding uniformity of care within a guidelines framework, medical and surgical outcomes, decreased visits, improved patient quality of life, cost containment, data collection and knowledge dissemination, trials of new therapeutics, and enhanced insurability have been achieved.

A detailed integration of caregivers and support was suggested by the 32nd Bethesda Conference, from primary care to patient advocacy groups to the highest levels of subspecialty resources. The pediatric cardiology team should be paired with adult cardiologists to facilitate transition of care for affected individuals. It was recommended that all ACHD patients have a provider who constitutes the medical "home," as well as at least 1 overreaching visit with a cardiologist with advanced training and experience with ACHD patients (4). A pattern of visits, follow-up, surgical care, subspecialty (catheterization, electrophysiology) cardiac and noncardiac care, emergent medical access, data coordination and dissemination, referral guidance, and education (with recognized regional variation) was suggested for ACHD patients and their caregivers based on the degree of medical complexity. Improvement in patient outcome was stressed via extension of physician caregiving by team-based clinical care associates (midlevel practitioners) with expertise in the management of ACHD patients.

The 32nd Bethesda Conference described 3 levels of training of adult cardiovascular specialists in terms of experience in ACHD (5). Task Force 9 covered training in the care of adult patients with CHD and differentiated 3 levels of training and expected expertise. These levels were subsequently incorporated into the COCATS (Core Cardiology Training Symposium) III document (6). Level 1 training consists of basic exposure to CHD patients and organized educational material on CHD. To enable proper recognition of the problems of adults with CHD and to be cognizant of when specialized referral is needed, all medical cardiology fellows should achieve level 1 training in CHD. Level 1 trainees should be instructed by a faculty member with level 2 or 3 training or its equivalent. A pediatric cardiologist should also be involved in these training programs.

Table 3. Types of Adult Congenital Heart Disease of Great Complexity*

Conduits, valved or nonvalved
Cyanotic congenital heart (all forms)
Double-outlet ventricle
Eisenmenger syndrome
Fontan procedure
Mitral atresia
Single ventricle (also called double inlet or outlet, common, or primitive)
Pulmonary atresia (all forms)
Pulmonary vascular obstructive disease
Transposition of the great arteries
Tricuspid atresia
Truncus arteriosus/hemitruncus
Other abnormalities of atrioventricular or ventriculoarterial connection not included above (ie, crisscross heart, isomerism, heterotaxy syndromes, ventricular inversion)

*These patients should be seen regularly at adult congenital heart disease centers.

Modified from Warnes CA, Liberthson R, Danielson GK, et al. Task force 1: the changing profile of congenital heart disease in adult life. J Am Coll Cardiol. 2001;37:1170–5 (3).

Table 4. Diagnoses in Adult Patients With Congenital Heart Disease of Moderate Complexity*

Aorto–left ventricular fistulas
Anomalous pulmonary venous drainage, partial or total
Atrioventricular septal defects (partial or complete)
Coarctation of the aorta
Ebstein's anomaly
Infundibular right ventricular outflow obstruction of significance
Ostium primum atrial septal defect
Patent ductus arteriosus (not closed)
Pulmonary valve regurgitation (moderate to severe)
Pulmonary valve stenosis (moderate to severe)
Sinus of Valsalva fistula/aneurysm
Sinus venosus atrial septal defect
Subvalvular AS or SupraAS (except HOCM)
Tetralogy of Fallot
Ventricular septal defect with:
Absent valve or valves
Aortic regurgitation
Coarctation of the aorta
Mitral disease
Right ventricular outflow tract obstruction
Straddling tricuspid/mitral valve
Subaortic stenosis

*These patients should be seen periodically at regional adult congenital heart disease centers.

Modified from Warnes CA, Liberthson R, Danielson GK, et al. Task force 1: the changing profile of congenital heart disease in adult life. J Am Coll Cardiol. 2001;37:1170–5 (3).

AS indicates aortic stenosis; HOCM, hypertrophic obstructive cardiomyopathy; and SupraAS, supravalvular aortic stenosis.

Level 2 training represents additional training for fellows who plan to care for adult patients with CHD so that they may acquire expertise in the clinical evaluation and management of such patients. Level 2 training generally requires 1 year of training in ACHD: either a 1-year formal program at a regional or tertiary care ACHD center or cumulative experience of 12 months through repetitive rotations or electives as a cardiology fellow with experienced ACHD cardiologists. This training should prepare the individual to be well-equipped for the routine care of even moderate to complex ACHD and to recognize when more advanced consultation or referral is advisable.

Level 3 training represents the level of knowledge needed by those graduates who wish to make a clinical and academic/research commitment to this field and not only become competent in the care of the entire spectrum of adult patients with CHD but also participate in the teaching and research of ACHD. Level 3 trainees generally require 2 years of training. These 24 months may either be consecutive or cumulative experience, and some recognition can be given to overall experience in CHD, be it pediatric, adolescent, or adult (eg, prior pediatric cardiology training or rotations). Such level 3 training would be sufficient to clinically manage the most complex ACHD patient in a regional or tertiary care center, to pursue an academic career, to train others in the field, or to direct an ACHD center program (6).

The 32nd Bethesda Conference report in 2000 highlighted the need for healthcare professionals, patients, and their families, together with regulatory agency representatives, to develop a strategic plan for organized advocacy for ACHD patients (3,4). This ACC/AHA Guideline Committee, working in parallel with but independently of a workgroup of the National Heart, Lung, and Blood Institute charged with recommending key research opportunities in ACHD patients, recognizes key actions that are currently and urgently required to improve care access for ACHD patients.

1.5.1. Recommendations for Access to Care

CLASS I

1. **An individual primary caregiver or cardiologist without specific training and expertise in ACHD should manage the care of adults with complex and moderate CHD (Tables 3 and 4) (7) only in collaboration with level 2 or level 3 ACHD specialists.** (4) (***Level of Evidence: C***)
2. **For ACHD patients in the lowest-risk group (simple CHD; Table 5), cardiac follow-up at a regional ACHD center is recommended at least once to formulate future needs for follow-up.** (***Level of Evidence: C***)
3. **Frequent follow-up (generally every 12 to 24 months) at a regional ACHD center is recommended for the larger group of adults with complex and moderate CHD. A smaller group of adults with very complex CHD will require follow-up at a regional ACHD center at a minimum of every 6 to 12 months.** (***Level of Evidence: C***)
4. **Stabilized adult patients with CHD who require admission for urgent or acute care should be transferred to a regional ACHD center, except in some circumstances after consultation with the patient's primary level 2 or level 3 ACHD specialist.** (4) (***Level of Evidence: C***)

Table 5. Diagnoses in Adult Patients With Simple Congenital Heart Disease*

Native disease
Isolated congenital aortic valve disease
Isolated congenital mitral valve disease (eg, except parachute valve, cleft leaflet)
Small atrial septal defect
Isolated small ventricular septal defect (no associated lesions)
Mild pulmonary stenosis
Small patent ductus arteriosus
Repaired conditions
Previously ligated or occluded ductus arteriosus
Repaired secundum or sinus venosus atrial septal defect without residua
Repaired ventricular septal defect without residua

*These patients can usually be cared for in the general medical community.
Modified from Warnes CA, Liberthson R, Danielson GK, et al. Task force 1: the changing profile of congenital heart disease in adult life. J Am Coll Cardiol. 2001;37:1170–5 (3).

5. **Diagnostic and interventional procedures, including imaging (ie, echocardiography, magnetic resonance imaging [MRI], or computed tomography [CT]), advanced cardiac catheterization, and electrophysiology procedures for adults with complex and moderate CHD should be performed in a regional ACHD center with appropriate experience in CHD and in a laboratory with appropriate personnel and equipment. Personnel performing such procedures should work as part of a team with expertise in the surgical and transcatheter management of patients with CHD. (*Level of Evidence: C*)**
6. **Surgical procedures that require general anesthesia or conscious sedation in adults with moderate or complex CHD should be performed in a regional ACHD center with an anesthesiologist familiar with ACHD patients. (*Level of Evidence: C*)**
7. **ACHD patients should be transferred to an ACHD center for urgent or acute care of cardiac problems. (*Level of Evidence: C*)**
8. **Adult patients with complex or high-risk CHD should be transferred to an ACHD center for urgent or acute noncardiac problems. (*Level of Evidence: C*)**
9. **An ACHD specialist should be notified or consulted when a patient with simple or low-risk CHD is admitted to a non-ACHD center. (*Level of Evidence: C*)**

After leaving the pediatric healthcare system, a percentage of ACHD patients do not succeed in achieving continuous cardiovascular care (8,9). Accordingly, ACHD patients are underserved compared with other heart disease populations. Barriers to healthcare access exist for ACHD patients, including the following:

- Failure to have guided transition from pediatric to adult care
- Lack of sufficient numbers of specialty clinics and regional centers
- Inadequate access to or availability of insurance (10)
- Insufficient education of patients and caregivers regarding disease nature and follow-up (11,12)
- Inadequate system of management of patient's cognitive or psychosocial impairment
- Inadequate infrastructure for case management.

1.5.2. Recommendations for Psychosocial Issues

CLASS I

1. **Individual and family psychosocial screening (including knowledge assessment of cardiac disease and management; perceptions about health and the impact of CHD; social functioning with family, friends, and significant others; employment and insurability status; and screening for cognitive, mood, and psychiatric disorders) should be part of the care of ACHD patients. Advanced practice nurses, physician assistants, psychologists, and social workers should play an integral role in assessing and providing for the psychosocial needs of ACHD patients. (*Level of Evidence: C*)**
2. **Informational tools should be developed before transfer from adolescent to adult care and used for patient/family education regarding CHD, including the following elements, to be provided in electronic format:**
   a. **Demographic data, including physician contact. (*Level of Evidence: C*)**
   b. **Description of CHD, surgeries, interventional procedures, and most recent diagnostic studies. (*Level of Evidence: C*)**
   c. **Medications. (*Level of Evidence: C*)**
3. **Additional health maintenance screening and information should be offered to ACHD patients as indicated during each visit to their ACHD healthcare provider, including the following:**
   a. **Endocarditis prophylaxis measures (refer to Section 1.6, Recommendations for Infective Endocarditis). (*Level of Evidence: C*)**
   b. **Exercise prescription, guidelines for exercise, and athletic participation for patients with CHD should reflect the published recommendations of the 36th Bethesda Conference report. (5) (*Level of Evidence: C*)**
   c. **Contraception and pregnancy information, including education regarding risk of CHD in offspring (for men and women). (*Level of Evidence: C*)**
   d. **General medical/dental preventive care (eg, smoking cessation, weight loss/maintenance, hypertension/lipid screening, oral care, and substance abuse counseling). (*Level of Evidence: C*)**
   e. **Recommended follow-up with cardiology. (*Level of Evidence: C*)**
4. **Vocational referral and health insurance information should be offered to ACHD patients during the transition period and refreshed at the time of their initial consultation in a tertiary referral center and intermittently as indicated by their social situation. (*Level of Evidence: C*)**
5. **A formal transition process should be used to provide optimal transfer of patients into ACHD care. This process should begin by 12 years of age and should be individualized on the basis of the patient's maturity level, with the goal being to transition and ultimately transfer the patient into adult care settings depending on the stability of the disease and psychosocial status. (*Level of Evidence: C*)**
6. **A psychological evaluation should be obtained if an adult's mental competency is in question and no appointed adult surrogate is available. (*Level of Evidence: C*)**
7. **All ACHD patients should be encouraged to complete an advance directive, ideally at a time during which they are not extremely ill or hospitalized, so that they can express their**

wishes thoughtfully in a less stressful setting and communicate these wishes to their families and caregivers. (*Level of Evidence: C*)

The degree of psychological impact caused by CHD remains ill defined. Results from decades of literature are divided with regard to the psychological functioning of ACHD patients. Methodologically, the challenges of controlling for medical, social, demographic, genetic, and cognitive variables that interact with psychological development make it difficult to draw general conclusions from studies (13,14); however, important clues regarding psychosocial outcomes have been useful in guiding medical therapy and thus form the foundation for comprehensive management of ACHD patients.

Early studies of psychosocial function dealt only with children and often reflected populations that confronted unrepaired CHD for longer periods of time. Thus, research focused on the "sick child" and recognized a recurrent theme of parental overprotection, as well as profiling the effect CHD had on the family unit (15,16). Maternal perceptions, accurate or not, were far more closely correlated to maladjustment in children than was medical severity of the child's illness (13,17). Intuitively, the psychopathology of children with CHD, imparted by physiological stress during early childhood, disruption of family dynamics, altered school and peer structure, and other unmet childhood milestones, may leave cognitive and psychological marks that carry over into adult life. Although there is evidence that argues for earlier reparative surgery to minimize childhood insecurities and morbidity (18), a correlation between the severity of CHD and psychological adjustment has not been substantiated (16,17,19–22). Moreover, new information is emerging about cognitive functioning in adolescents who underwent surgical repair in infancy with cardiopulmonary bypass that indicates some deficits in planning and self-management (23–27). Long-term behavioral outcome studies after the neonatal arterial switch operation (ASO) for transposition of the great arteries (TGA) have demonstrated highly specific disabilities that might impact the quality of self-care (28). Longer survival and decreasing morbidity among ACHD patients has made quality-of-life issues much more central to the understanding and management of this population (14,29–39). Some quality-of-life issues pertinent to ACHD patients, regardless of severity of disease, include independent living arrangements, education, employment, sports, health and life insurance acquisition, contraception, genetic counseling, and pregnancy concerns (40).

Circumstantial depression and anxiety are understandable in older adolescents and young adults with chronic health problems. One pilot study suggests that up to one third of ACHD patients may have a psychiatric disorder, with depression and anxiety being most prominent (41), whereas only 20% of the general population are afflicted with psychiatric illness (42). Accordingly, a careful assessment of depressive symptoms and their possible overlap with symptoms of medical illness or side effects of medications must be part of the clinical evaluation of ACHD patients (13,14).

1.5.3. Transition of Care

Physical and emotional maturity is the primary requirement for transfer of adolescent or young adult patients into adult care environments. The age at which this occurs varies and may range from the mid-teens to the mid-20s, depending on the patient. However, the process of transitioning, that is, preparing young patients for successful transfer to an adult healthcare provider at a later time, should begin by the age of 12 years (43).

Strategies for transfer of patients with CHD into adult care settings are well described (44,45) and use a stepwise approach to establishing autonomy and understanding one's cardiac problem and lifestyle issues important to long-term stability of CHD. Pediatric clinicians can reinforce autonomy by focusing their communication on the patient, so that the teen years serve as an ongoing "workshop" in which the ultimate goal is accepting ownership of and responsibility for one's cardiac disease. Parents should take an active role in fostering independence in their teenagers. The use of support groups and educational meetings geared toward parents and ACHD patients offers a prime opportunity for parents to discuss their fears and openly communicate reality-based strategies for approaching difficult topics with their children. National support organizations for CHD and ACHD patients now exist and provide resources for families (eg, the Congenital Heart Information Network and the Adult Congenital Heart Association). Regional tertiary centers for the care of ACHD patients may also provide conferences that serve this purpose. Some centers provide transitional support meetings so that adolescents and parents can familiarize themselves with the goals of ACHD care. Despite the availability of structured resources for parents, patients, and families with CHD, the ultimate responsibility still rests with clinicians to meet the educational needs of their young patients. Topics that should be discussed early in childhood and repeatedly through the teens, 20s, and beyond include a description of the cardiac defect and surgeries (including use of diagrams); medications; exercise prescription; risk modification; health maintenance and follow-up recommendations; vocational and educational recommendations; insurance information; and information about genetics, contraception, and pregnancy. This information should be given in verbal and written form and provided to the patient in an electronic or paper format (45,46). This is a reference tool that can be a constant resource for the patient long term and can assist healthcare providers who are not familiar with the patient. The use of advanced practice nurses and physician assistants in pediatric and ACHD settings optimizes the facilitation of the transition process from pediatrics to adult cardiology, identification of patient needs, screening and referral for psychosocial problems, and education and counseling of patients and families (47).

Pertinent medical records, including diagrams of cardiac defects and operations, operative and procedural reports, recent physical examination, electrocardiograms (ECGs), and echocardiograms, should be provided to all cardiologists involved in the care of a patient with CHD. In addition, once patients are properly educated and aware of basic terminology pertaining to their own cardiac status, they should be

offered copies of their medical reports, which implies and imparts responsibility and autonomy regarding their condition.

1.5.4. Exercise and Athletics

Exercise restrictions correlate with internalization of fear in young people with CHD (48). The ability to exercise is a fundamental measure of quality of life, perceived capacity for social acceptance, employment, sexual relations, and procreation. Young people with CHD may experience exercise limitations for many reasons, including their underlying cardiac reserve, physical deconditioning, and lack of exercise experience in childhood; poor coordination related to coexisting disabilities; misperceptions about restrictions; lack of interest; and anxiety (43,44). Current symptoms only account for approximately 30% of all barriers to exercise. Recommendations regarding physical training, exercise, and athletics are core to the comprehensive patient education that should begin by early adolescence. An individual exercise prescription (one that accounts for physical limitations, developmental challenges, risk modification, health concerns such as obesity, and personal preferences) needs to be provided and updated regularly so that the beneficial utility of exercise is not lost among a list of restrictions. Guidelines for physical activity and exercise in patients with CHD are outlined in the 36th Bethesda Conference in "Eligibility: Recommendations for Competitive Athletes with Cardiovascular Abnormalities." (49) Currently, however, there are few data concerning activity guidelines for the nonathlete.

The finding of diminished aerobic capacity in all groups with CHD (50–58) validates the importance of comparative testing over time in patients until reference values can be researched further (54). However, improved oxygen uptake during exercise is only 1 parameter of the effect of training and cannot be used alone to determine whether the main goals of exercise have been achieved (59). Beyond improved oxygen consumption and tolerance of physical activity, physical training of children and adolescents can also result in decreased withdrawal and somatic complaints (60,61). This supports the need for organized exercise programs for young people with CHD, particularly adolescents who view physical activity as the defining focus of a healthy lifestyle despite restrictions from competitive athletics.

1.5.5. Employment

Entering the job market and establishing a career is arguably the most important developmental milestone of a young adult's life (30). Careful consideration of the individual's physical, mental, and psychological disposition will help in identifying the right career choice. This is a discussion that should include the cardiologist, so that realistic limitations are explored and misconceptions eliminated. Vocational planning should take place early in adolescence so that appropriate educational options can be pursued long before the patient enters the work force. Ideally, cognitive evaluation should be performed at or before 5 years of age so that the appropriate educational track can be determined. Early childhood intervention has been shown to result in improved employment status during adult life (62). The goal of clinicians caring for those with CHD should be to view every patient as employable and avoid the temptation to accept the status quo when a patient is receiving social security disability income or other disability assistance through Medicaid or Medicare. Governmental assistance programs may perpetuate long-term disability for those fearful of losing their health insurance coverage (63). Reports from more than a decade ago projected that approximately 10% of ACHD patients would be totally disabled (64). Furthermore, 8% to 13% of ACHD patients were receiving public assistance or living as a dependent with relatives (64,65). Important legislation has focused on bringing individuals with disabilities into the work force. Ultimately, with improving longevity in patients with CHD and better surgical outcomes, the proportion of physically disabled ACHD patients is expected to decrease.

Seeking assistance from the state employment development department (the names of these programs vary from state to state) can be an important step in finding jobs for adults with disabilities. These programs offer job and training referrals, counseling, and job search assistance and workshops. Federal programs provide for vocational rehabilitation for disabled individuals, as well as hiring and placement into jobs appropriate for their level of disability.

The Americans With Disabilities Act of 1990 prohibits discrimination with respect to hiring, promotion, or termination of employees on the basis of disability. Therefore, ACHD patients are not required to disclose their cardiac condition to a prospective employer unless physical restrictions imposed by their cardiac disease would limit their ability to satisfy the job description (63). The Family and Medical Leave Act of 1993 states that covered employers must grant eligible employees up to a total of 12 workweeks of unpaid leave during any 12-month period when the employee is unable to work because of a serious health condition or to take care of an immediate family member with a serious health condition (66).

The Work Incentives Improvement Act of 1999 (also known as the Medicaid Buy-In Program) is designed to promote employment and economic self-sufficiency for individuals with disabilities. Under this federal legislation, states can amend their Medicaid programs to enable individuals with disabilities to obtain coverage under Medicaid while giving incentives for these individuals to seek and maintain employment. Advocates in each ACC and AHA chapter should work with state Medicaid programs and state legislators to define appropriate health disabilities eligible for coverage (10).

1.5.6. Insurability

In the 1990s, studies indicated that up to 20% of ACHD patients were uninsured and that most health insurance policies were individual plans rather than group policies. The heterogeneity of CHD over the life span contributes to the difficulties faced by insurers when assigning risk. Regional tertiary centers specializing in the care of ACHD patients must collaborate in multicenter studies to define and publish survival data in a format amenable to life-table analysis (67). In addition, the use of clinical practice guidelines, such as those outlined in this ACC/AHA document, will further direct

insurers, primary care providers, and cardiologists on the appropriate use of diagnostic testing, as well as the appropriate time for referral.

Today, the most affordable way to obtain health insurance is via a group policy, through one's employer, or with health management organizations. With national attention now focused on the need for regional tertiary care for patients with complex CHD, health maintenance organizations are being held accountable for finding appropriate specialized care for ACHD patients. Patients, with their physician's support, need to be their own advocates within the health maintenance organization system and demand referrals if they believe their cardiologist is ill equipped to manage their complex cardiac care. National patient support organizations such as the Adult Congenital Heart Association have made it their mission to educate adults via newsletters, the Internet, and the like about the need for specialized cardiac care in ACHD patients with moderate to severe disease, and they provide an extensive referral network of ACHD specialists.

Currently, at least 30 states offer high-risk health insurance plans through "risk pools." This provides a safety net for individuals who are denied health insurance because of a preexisting medical condition. More than 250 000 enrollees have been able to obtain comprehensive health insurance protection via these risk pools since the first pools were started in 1976. Risk pools are state created, are nonprofit, and usually do not require tax dollars for operational purposes. Eligible individuals must prove state residency and prove they have been rejected for similar health insurance with similar premiums by at least 1 insurer. Healthcare providers caring for ACHD patients should be aware of options available in their state. Healthcare providers need to give accurate health information to insurers in a prompt fashion so that a fair evaluation of the patient's risk status can be made.

Health and life insurance can be elusive to ACHD patients. Regardless of severity, ACHD patients face a significantly higher risk of being denied life insurance than their peers without CHD (10,40,68). Recent studies found that more than one third of ACHD patients were refused life insurance compared with 4% of age-matched peers without CHD, with no regard to severity of defect (40). A useful resource for state-by-state consumer guidelines about getting and keeping health insurance can be accessed via the Internet at www.healthinsuranceinfo.net.

1.5.7. Congenital Syndromes

Congenital syndromes, including coexisting neurological and cognitive deficits, can further complicate the psychological and social adjustment of ACHD patients. Approximately 18% of congenital heart defects are associated with a congenital syndrome or chromosomal abnormality (69). Among chromosomal abnormalities in infants with cardiovascular defects, 81% are Down syndrome, which has a CHD prevalence of 40%. Adults with Down syndrome represent a growing number of the patients seen in tertiary ACHD clinics and require careful attention to coexisting diseases and special care issues. Hypothyroidism, leukemia, Alzheimer's disease, depression, atlantoaxial subluxation, obesity, and sleep apnea are common in Down syndrome, and regular screening for these ailments should be performed. Often, sedation or general anesthesia is necessary for routine procedures, such as dental cleaning, Pap smears, or prolonged diagnostic procedures that require immobility. The risks of anesthesia and procedures need to be carefully reviewed by CHD specialists and discussed with the patient.

Approximately 15% of patients with tetralogy of Fallot and other conotruncal defects have chromosome 22q11.2 deletion, most commonly manifested as DiGeorge syndrome but also presenting as velocardiofacial (Shprintzen) syndrome and conotruncal anomaly face (Takao) syndrome (70). Patients with a history of type B interrupted aortic arch or truncus arteriosus also have a high incidence of DiGeorge syndrome. Many patients with this chromosome deletion show impairment in social function. Coexisting diseases associated with these overlapping syndromes include schizophrenia, mental disability, deafness, immune deficiencies, endocrinopathies, and clubbed foot (70).

Williams syndrome is a developmental disorder that involves connective tissue, the central nervous system, and supravalvular AS (SupraAS); it has been associated with a chromosome deletion in band 7q11.23 (70). Most Williams syndrome patients have a lack of social inhibition and some degree of mental disability that complicates planning and self-management. Adults with other syndromes, including Noonan and Turner syndromes, have varying degrees of cognitive deficits. Patients with Turner syndrome have a variety of noncardiovascular problems, including ovarian and thyroid disorders, inflammatory bowel disease, pigmented and melanotic nevi, and sensorineural deficits.

Because the cardiologist may be the only regular healthcare provider for adults who have congenital syndromes and chromosomal abnormalities in association with their CHD, careful screening and appropriate referrals (such as endocrinology, genetic counseling, psychiatry, and vocational rehabilitation) should take place. Because of the multiplicity of comorbidities and the potential for impact on cardiovascular management, there should be clarity about which healthcare provider is serving as the medical "home." Whenever possible, the ACHD specialist should work closely with a primary physician who accepts this responsibility. Although many of these patients are dependent on others for long-term care, some are able to live independently and require sensitive counseling regarding healthcare maintenance and risks. Advice regarding sexual activity and contraception is essential, even if the patient does not request it. Genetic counseling should be offered to all patients.

1.5.8. Medical/Ethical/Legal Issues

Some ACHD patients, especially those with associated syndromes, may be incapable of providing informed consent to the degree that meets ethical and legal standards of understanding their situation, understanding the risks associated with the decision at hand, and communicating a decision based on that understanding. Adults who may require a legal surrogate to facilitate informed consent are those who are cognitively impaired, such as those with Down syndrome, and those with impaired consciousness due to severe illness.

If an adult's mental competency is in question, and no appointed adult surrogate is available, a psychological evaluation should be requested (63). The issue of legal guardianship in adults with significant mental disability becomes an ethical and legal challenge when 1 or both parents die or become incapacitated by illness with no accommodation for transfer of guardianship. Guidance in addressing these issues should be included as part of the transition education and reinforced thereafter.

Advance directives can assist family members and healthcare providers in understanding a patient's wishes if they are incapable of speaking for themselves (71). All ACHD patients should be encouraged to complete an advance directive, ideally at a time during which they are not morbidly ill or hospitalized, so that they can express their wishes in a less stressful setting.

1.6. Recommendations for Infective Endocarditis

CLASS I

1. **ACHD patients must be informed of their potential risk for IE and should be provided with the AHA information card with instructions for prophylaxis. (*Level of Evidence: B*)**
2. **When patients with ACHD present with an unexplained febrile illness and potential IE, blood cultures should be drawn before antibiotic treatment is initiated to avoid delay in diagnosis due to "culture-negative" IE. (*Level of Evidence: B*)**
3. **Transthoracic echocardiography (TTE) should be performed when the diagnosis of native-valve IE is suspected. (*Level of Evidence: B*)**
4. **Transesophageal echocardiography (TEE) is indicated if TTE windows are inadequate or equivocal, in the presence of a prosthetic valve or material or surgically constructed shunt, in the presence of complex congenital cardiovascular anatomy, or to define possible complications of endocarditis (eg, sepsis, abscess, valvular destruction or dehiscence, embolism, or hemodynamic instability). (72) (*Level of Evidence: B*)**
5. **ACHD patients with evidence of IE should have early consultation with a surgeon with experience in ACHD because of the potential for rapid deterioration and concern about possible infection of prosthetic material. (*Level of Evidence: C*)**

CLASS IIa

1. **Antibiotic prophylaxis before dental procedures that involve manipulation of gingival tissue or the periapical region of teeth or perforation of the oral mucosa is reasonable in patients with CHD with the highest risk for adverse outcome from IE, including those with the following indications:**
   a. **Prosthetic cardiac valve or prosthetic material used for cardiac valve repair. (*Level of Evidence: B*)**
   b. **Previous IE. (*Level of Evidence: B*)**
   c. **Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: B*)**
   d. **Completely repaired CHD with prosthetic materials, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure. (*Level of Evidence: B*)**
   e. **Repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device that inhibits endothelialization. (*Level of Evidence: B*)**
2. **It is reasonable to consider antibiotic prophylaxis against IE before vaginal delivery at the time of membrane rupture in select patients with the highest risk of adverse outcomes. This includes patients with the following indications:**
   a. **Prosthetic cardiac valve or prosthetic material used for cardiac valve repair. (*Level of Evidence: C*)**
   b. **Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: C*)**

CLASS III

1. **Prophylaxis against IE is not recommended for nondental procedures (such as esophagogastroduodenoscopy or colonoscopy) in the absence of active infection. (*Level of Evidence: C*)**

The clinical setting and presentation of endocarditis have changed over the last 50 years, in part owing to technical advances (eg, cardiac surgery, hemodialysis), the use of prosthetic devices and indwelling lines, the increasing prevalence of intravenous drug abuse, the emergence of resistant organisms, and the continued development of increasingly potent antibiotics (73–78). True surgical cures of congenital cardiovascular disorders are infrequent, and almost all patients who have undergone surgery are left with some form of residua or sequelae, many of which predispose to IE (73,74,77–82).

Epidemiological studies of IE have reported underlying CHD in 11% to 13% of cases (83,84). Li and Somerville reported that IE accounted for 4% of admissions to a specialized adult congenital heart service (85). Including pediatric data, certain unoperated and operated cardiac lesions may be more susceptible to infection (Table 6). Tetralogy of Fallot, TGA, unrepaired ventricular septal defect (VSD), patent ductus arteriosus (PDA), and bicuspid aortic valves (BAVs) with aortic valve stenosis or aortic regurgitation (AR) are susceptible to IE. (73,74,79,81,86–102) Patients who have had surgical palliation of CHD (eg, systemic–to–pulmonary artery shunts) or various types of reparative surgery (often requiring prosthetic materials or valves, conduit insertion, or conduit replacement) have major predisposing conditions for IE (74,79,81,103).

The Second Natural History Study of Congenital Heart Defects reported on the incidence of IE in young adults with aortic stenosis (AS), pulmonary stenosis (PS), and VSD (104). The incidence rate was nearly 35-fold the population-based rate; *viridans streptococcus* was the predominant organism. The stenotic pulmonary valve was rarely affected, with only 1 case in this series. For VSDs, the risk of IE before surgical closure was more than twice that for the surgically closed VSD. In addition, the presence of AR independently increased the risk of IE in patients with VSD, whether managed medically or surgically. Of those with a surgically repaired VSD who developed IE, at least 22% were known to have a residual VSD leak.

Li and Somerville (85) reported IE in the grown-up congenital heart population comprising 185 patients (214 episodes) during 2 periods, 1983 to 1993 and 1993 to 1996, divided into unoperated or palliated (group I) and operated definitive repair or valve repair/replacement (group II). They noted no IE in atrial septal defect (ASD), closed VSD, patent

Table 6. Cardiac Conditions Associated With the Highest Risk of Adverse Outcome From Endocarditis for Which Prophylaxis With Dental Procedures Is Reasonable

Condition	Congenital Specific Condition*
• Previous infective endocarditis	• Unrepaired cyanotic CHD, including palliative shunts and conduits
• Prosthetic cardiac valve or prosthetic material used for cardiac valve repair	• Completely repaired congenital heart defect with prosthetic material or device, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure†
	• Repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device that inhibit endothelialization
	• Cardiac transplant recipients who develop cardiac valvulopathy

*Except for the conditions listed above, antibiotic prophylaxis is no longer recommended for any other form of CHD.

†Prophylaxis is reasonable because endothelialization of prosthetic material occurs within 6 months after the procedure.

Modified with permission to include footnotes from Wilson et al. Prevention of infective endocarditis: guidelines from the American Heart Association: a guideline from the American Heart Association Rheumatic Fever, Endocarditis, and Kawasaki Disease Committee, Council on Cardiovascular Disease in the Young, and the Council on Clinical Cardiology, Council on Cardiovascular Surgery and Anesthesia, and the Quality of Care and Outcomes Research Interdisciplinary Working Group. Circulation. 2007;116:1736–54 (72).

CHD indicates congenital heart disease.

ductus, isolated PS, or unrepaired Ebstein's anomaly or after Fontan-type or Mustard operations. IE in group I was most commonly represented by VSD (24%), left ventricular outflow tract (LVOT) lesions (17%), and mitral valve disorders (13%) and in group II by LVOT lesions (35%), repaired tetralogy of Fallot (19%), and atrioventricular (AV) defects (14%). Of the 185 patients, 87 (47%) had a known predisposing event (dental procedure or sepsis in group I, 33%; cardiovascular surgery in group II, 50%). Diagnosis was delayed (from onset of symptoms to time of diagnosis) in group I by 60 days and in group II by 29 days.

Niwa et al in 2005 (105) reported IE in 170 pediatric and 69 adult patients from 1997 to 2001. They noted prior cardiac surgery in 199 patients with IE, 88 of whom had surgery for cyanotic cardiovascular malformations. IE was left-sided in 46% and right-sided in 51%; the most common organisms were streptococci (50%) and staphylococci (37%). Surgery during IE was needed in 26% for large vegetations (45%) and heart failure (29%). Complications were seen in 48.5%. Mortality was 8% for medical treatment alone and 11.1% for those who also required surgery. In 33.3% of patients, conditions and procedures associated with IE were identified that preceded IE; the most common were dental manipulation (37.2%) and cardiovascular surgery (25.6%), followed by pneumonia (14.1%). Of these cases, only 28.2% had received antibiotic prophylaxis.

Di Filippo et al reported in 2006 (106) on 153 episodes of IE in CHD diagnosed with the revised Duke criteria, showing an increasing rate with 81 episodes from 1966 to 1989 (3.5 per year) and 72 episodes from 1990 to 2001 (6 per year). During the second period, there were more adults (40% later versus 9% earlier). Of interest, CHD was known in 122 patients before IE but was unrecognized in 31. Of the 153 episodes of IE, 39 occurred in patients who had repaired lesions, 35 in patients who had palliation (usually complex disease), and 79 in patients who had unoperated CHD. Tetralogy of Fallot with IE decreased from 12% to 3%, and complex cyanotic disease increased from 14% to 28%; the proportion of aortic valve anomalies and small VSDs increased. Dental procedures as a presumed cause of IE were more common during the later period (33% versus 20% earlier), cutaneous infection rose to 17% (from 5% earlier), and postoperative infection appeared less frequently later (11%) than earlier (21%). The streptococcus group continued to represent the most prevalent organisms, followed by staphylococci. Their data emphasized that current targets of prevention of IE should include complex cyanotic lesions, lesions repaired with prosthetic material, and small VSDs.

The pathogenesis of IE in part requires damaged or traumatized endothelium and a portal of entry of bacteria into the bloodstream. Bacteria may bind to platelets in the blood pool and then be deposited at the site of vascular endothelial damage. The infective lesion usually occurs at the low-pressure end of a high-gradient lesion at the site of impact of a high-velocity jet. For example, vegetations in conjunction with aortic coarctation may occur in the downstream descending aorta. With aortic valve disease, not only may vegetations occur on the ventricular surface of the valve, but the regurgitant jet impacting on the mitral valve may cause secondary vegetation. Usual sites of vegetations with a restrictive VSD occur where the high-velocity left-to-right jet impacts on the right side of the heart (ie, tricuspid valve septal leaflet or mural RV endocardium). The consequences of the infective vegetation depend on the site or structure involved and the virulence of the organism. Valvular destruction with significant valvular regurgitation or fistulous connections can cause heart failure. Endarteritis (as with patent ductus and coarctation) can cause aneurysm formation with potential for rupture. Embolization of vegetative material can cause arterial obstruction (eg, stroke) and possible abscess formation, and right-sided embolization to the lung can mimic pneumonia. Immunologic reactions can trigger glomerulonephritis or vasculitis as a result of the deposition of circulating immune complexes in the small vessels in skin (Janeway lesion and Osler node) (75).

Many cases of clinically suspected IE are difficult to diagnose with certainty because of altered immune response, prior antibiotic exposure, or indolent organisms and in some patients with acute right-sided IE in whom the systemic and immune responses have not developed (73,75,76,80,81). Now widely accepted, Durack et al incorporated 2-dimensional echocardiography as a means of demonstration of vegetations (77,107). The Duke criteria defined 2 major criteria (positive

Table 7. Congenital Cardiac Lesions and Perioperative Risk for Noncardiac Surgery

High risk
Pulmonary hypertension, primary or secondary
Cyanotic congenital heart disease
New York Heart Association class III or IV
Severe systemic ventricular dysfunction (ejection fraction less than 35%)
Severe left-sided heart obstructive lesions
Moderate risk
Prosthetic valve or conduit
Intracardiac shunt
Moderate left-sided heart obstruction
Moderate systemic ventricular dysfunction

blood culture with typical microorganisms and evidence of endocardial involvement, eg, a typical vegetation on an echocardiogram) and 6 minor criteria (ie, predisposition, fever, vascular phenomena, immunologic phenomena, suggestive microbiological evidence, and echocardiographic findings consistent with endocarditis but not meeting major echocardiographic criteria), with categories defined as definite, possible, and rejected (107). Echocardiography is crucial in the diagnosis of IE. In general, a TTE study is useful in confirming the presence of vegetation, but often, the sensitivity is too low to rule out its absence. If a TTE study is equivocal, or in the presence of a prosthetic valve or complex congenital cardiovascular anatomy in which transthoracic windows may be inadequate, TEE is indicated (73 to 79, 81, 108 to 112). TEE is particularly important in the search for IE in the adolescent and adult for evaluation of the thoracic aorta, ventricular outflow tracts, and valved conduits and for visualization of the entire ventricular septum. Given the complexity of many of the malformations and the wide array of surgical palliations and repairs, however, performance and interpretation of echocardiography must be done by those with expertise in the native and altered postoperative (109) anatomy (103,108,110–112).

A delay in diagnosis of IE carries the risk of significant morbidity and mortality. A high index of suspicion for IE in any patient with operated or unoperated CHD is a key to early diagnosis (74,78,79,81,103,113–115). Cardiac lesions and their relative risk of developing IE are listed in Table 7.

An antecedent event is identified in a minority of cases with IE (74,79). Awadallah et al identified predisposing events in 56%, with unprotected dental work, recent open heart surgery, and skin infections being the most common (116). Gersony et al found that an antecedent event could be identified in 32% of cases; these events included dental work, previous bacterial infection (ie, pharyngitis, sinusitis, enteritis, or pelvic inflammatory disease), and cardiac catheterization (101).

Additional issues more specific for patients with CHD and risk for IE may not be well recognized by many practitioners (72,74,78–80). Patients with unoperated cyanotic heart disease frequently have acne or have spongy, friable gums; appropriate care is necessary to diminish the risk of bacteremia. Epistaxis and hemoptysis are frequent in the cyanotic patient; nasal cautery may be a risk factor for IE. Nail biting is a problem, with the possibility of local infection being a focus for bacteremia. High-risk behaviors (eg, intravenous drug abuse, body piercing, or tattoos) not uncommon in adolescents and young adults in particular are well-known risk factors, especially for acute staphylococcal IE on the right side of the heart, and the patient should be informed of the risks of these activities. The use of intrauterine devices for female contraception is somewhat controversial because of concern about endocarditis, although the rate of infection is only approximately 1.4 times normal, provided that sexual relationships are monogamous. The AHA recommendations do not advise antibiotic prophylaxis for patients before genitourinary procedures, but because of the high risk for adverse outcome in patients with prosthetic cardiac valves and those with cyanotic CHD and the potential for infection in the setting of a complex vaginal delivery, this committee proposed that antibiotics might be considered in those high-risk patients at the time of membrane rupture (recognizing that proof of efficacy of prophylaxis is not available) (117).

In all cases of IE, cultures should be obtained to try to establish the causative organism before antibiotics are initiated (73,75,78,82,112). CHD patients who present with fever and potential IE should have blood cultures drawn before antibiotic therapy is initiated to avoid subsequent false-negative blood cultures (78,103,118). Recognizing that initial therapy is usually parenteral and usually intravenous, one should recall that cyanotic patients with right-to-left shunts have the possibility of "paradoxical" systemic embolization and, as such, risk of stroke. Air filters should be used on the line with meticulous attention to avoiding injection of air bubbles. Details of all aspects of medical and antimicrobial management of IE are beyond the scope of this review and are addressed by a separate AHA working group, as well as other authors (78,81,99,119,120). Collaboration with an infectious disease specialist is invaluable. Prompt referral of the adult patient with CHD to a specialized center is usually indicated because hemodynamic deterioration may be rapid, and surgical treatment of often complicated anatomy and/or reoperation may be required (78,82). Early consultation with a cardiac surgeon with experience treating adults with CHD is appropriate. Surgical intervention is considered in patients with uncontrolled congestive heart failure, continued emboli, medically uncontrolled infection, prosthetic material infection, and development of heart block (73,75,78,80,112–114,121). Management decisions regarding infected prosthetic valves or conduits in which the duration of preoperative antibiotic therapy must be balanced against the risk of reoperation must be made in collaboration with the surgeon. Ultimately, to reduce costs without risking efficacy, prolonged home parenteral antibiotics may be required after the initial inpatient hospitalization.

Prevention of IE includes nonchemotherapeutic and chemotherapeutic methods (74,75,78,80,81,103). Clinical judgment and discretion are required. It is always worthwhile to strive to provide evidence-based medical care. However, the Cochrane Collaboration did not provide evidence proving whether or not penicillin prophylaxis is effective protection against bacterial endocarditis in those with lesions considered

at risk for development of IE and who were about to undergo an invasive dental procedure. They also noted that there is lack of evidence to support published guidelines in this area or to show whether the potential harm or cost of penicillin outweighs the benefit (122).

On the basis of a "revised" assessment regarding the risk of bacteremia-induced endocarditis, new guidelines for the prevention of endocarditis were published in 2006 by the Working Party of the British Society for Antimicrobial Chemotherapy (123). The 2006 guidelines recommend that antimicrobial prophylaxis for dental procedures be confined to those with (1) previous IE, (2) prosthetic cardiac valves, or (3) surgically constructed pulmonary shunts or conduits. In contrast, for bacteremic nondental procedures, the 2006 group expanded the "dental risk" list to also include (4) complex CHD (except not secundum ASD, which is presumably isolated and uncomplicated), (5) complex LVOT obstruction, including AS and BAVs, (6) acquired valvulopathy, and (7) mitral valve prolapse in the presence of echocardiographic "substantial leaflet pathology and regurgitation." The British Society for Antimicrobial Chemotherapy justifies its decisions by shifting the emphasis from "procedure-related bacteremia" to "cumulative bacteremia."

The 2007 AHA guidelines for the prevention of endocarditis have substantially changed the recommendations for antibiotic prophylaxis on the basis of a consensus of expert opinions (72). The new, simplified recommendations are based on the proposition that most bacteremia occurs during activities of daily living, that IE is more likely to result from long-term cumulative exposure to these daily random bacteremias than from procedural bacteremias, and that proof is lacking that prophylaxis prevents any (or at most a very small number) cases of IE. They posit that the risks of antibiotic adverse events in the patient (allergic reactions) and the emergence of resistant organisms exceed any proven benefit of antibiotic prophylaxis against IE.

The new AHA guidelines appropriately emphasize maintenance of oral health and hygiene to reduce daily bacteremia and underscore that this is more important than any dental antibiotic prophylaxis. Accordingly, the 2007 AHA writing committee for the updated guidelines on prevention of endocarditis concluded that antibiotic prophylaxis for dental procedures likely to induce procedural bacteremia (those that involve manipulation of gingival tissue or the periapical region of the teeth or perforation of the gingival mucosa) should be confined to cardiac conditions associated with the most significant adverse outcomes should IE develop (72). They included in this group those with previous IE; those with prosthetic cardiac valves or surgically constructed conduits or shunts; those with unrepaired cyanotic CHD or CHD repaired with prosthetic material or devices (until 6 months after the procedure); those with repaired CHD with residual defects at or adjacent to the site of a prosthetic patch or device; and cardiac transplant patients who develop valvulopathy. They specifically recommend no IE prophylaxis before gastrointestinal or genitourinary procedures, a major departure from previous guidelines. The new AHA guidelines have engendered some considerable controversy and may violate long-standing patient and provider expectations and practice. Concern has been expressed that changes in preexisting recommendations were not based on new data or randomized trials and that absence of proof of efficacy and safety cannot be used as proof of absence of efficacy and safety of antimicrobial prophylaxis (124). The present ACHD Guideline Committee understands that there may be reluctance to deviate from prior recommendations for patients with some forms of CHD. This reluctance may be especially true for patients with BAV or coarctation of the aorta. In select circumstances, the committee understands that some clinicians and some patients may still feel more comfortable continuing with IE prophylaxis. Accordingly, this committee recommends that healthcare providers discuss the rationale for these new changes with their patients, including the lack of scientific evidence demonstrating proven benefit for IE prophylaxis. In those settings, the clinician should determine that the risks associated with antibiotics are low before continuing a prophylaxis regimen. Over time, and with continuing education, the committee anticipates growing acceptance of the new guidelines among both provider and patient communities.

This ACHD writing committee proposes that the "high-risk" group in whom it is reasonable to give antibiotic prophylaxis before dental procedures would include the following: (1) those with a prosthetic cardiac valve; (2) those with prior IE; (3) those with unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits; (4) those with repaired CHD with prosthetic material or device, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure; and (5) those with repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device that inhibit endothelialization.

We emphasize that nonchemotherapeutic methods are particularly important in the adolescent or young adult patient with CHD, among whom nail biting, acne, and problems with dental health are common. Oral prevention starts with meticulous oral care and routine preventive care by a dentist or oral hygienist. A patient with cyanotic heart disease often has spongy, friable gums, and a soft-bristle toothbrush must be used. Female contraception should be planned with the risks and benefits of intrauterine devices kept in mind.

The patient's knowledge of the need for and the type of IE prophylaxis is also an important issue (77,103,125). Caldwell et al noted that fewer than 50% of families knew about endocarditis prevention or precautions, and even fewer understood why prophylaxis was considered indicated (91). Cetta and Warnes reported in 1995 from their specialized ACHD clinic that those with CHD had inadequate knowledge about their cardiac lesion, about IE, and about prophylaxis (125). With aggressive education in their clinic, patient knowledge improved, but they emphasized that educational efforts need to be reinforced regularly. A patient should be given a detailed explanation of his or her diagnosis and the rationale for IE prevention, and the patient's specific regimen for dental procedures should be provided. Information about the signs and symptoms of IE should also be provided. At every subsequent visit, it should again be verified that the

patient knows what is required for dental care and prophylaxis (74).

1.7. Recommendations for Noncardiac Surgery

CLASS I

1. **Basic preoperative assessment for ACHD patients should include systemic arterial oximetry, an ECG, chest x-ray, TTE, and blood tests for full blood count and coagulation screen. (*Level of Evidence: C*)**
2. **It is recommended that when possible, the preoperative evaluation and surgery for ACHD patients be performed in a regional center specializing in congenital cardiology, with experienced surgeons and cardiac anesthesiologists. (*Level of Evidence: C*)**
3. **Certain high-risk patient populations should be managed at centers for the care of ACHD patients under all circumstances, unless the operative intervention is an absolute emergency. High-risk categories include patients with the following:**
   a. **Prior Fontan procedure. (*Level of Evidence: C*)**
   b. **Severe pulmonary arterial hypertension (PAH). (*Level of Evidence: C*)**
   c. **Cyanotic CHD. (*Level of Evidence: C*)**
   d. **Complex CHD with residua such as heart failure, valve disease, or the need for anticoagulation. (*Level of Evidence: C*)**
   e. **Patients with CHD and malignant arrhythmias. (*Level of Evidence: C*)**
4. **Consultation with ACHD experts regarding the assessment of risk is recommended for patients with CHD who will undergo noncardiac surgery. (*Level of Evidence: C*)**
5. **Consultation with a cardiac anesthesiologist is recommended for moderate- and high-risk patients. (*Level of Evidence: C*)**

Performance of any surgical procedure in ACHD patients carries a greater risk than in the normal population. Certain surgical procedures are frequently required in cyanotic patients, such as intervention for gallstones, scoliosis, and, less commonly, cerebral abscess. The risk for noncardiac surgery depends on the nature of the underlying CHD, the extent of the procedure, and the urgency of intervention. Table 7 lists lesions at moderate and high risk for noncardiac surgery.

A thorough evaluation of the patient with CHD should be undertaken before anticipated noncardiac surgery. Basic preoperative assessment includes an ECG, chest x-ray, TTE, and blood tests for full blood count and coagulation screen. It is recommended, when possible, that the preoperative evaluation and surgery be performed in an ACHD center by experienced surgeons and cardiac anesthesiologists. This allows close perioperative follow-up by an ACHD specialist. The specialist team should always be involved in the care of the complex and cyanotic adult patient with CHD, because this minimizes avoidable errors that can cause important morbidity or even death (126).

Select high-risk patient populations should be managed at centers for the care of ACHD patients under all circumstances, unless the operative intervention is an absolute emergency. These patients include those with prior Fontan procedure, severe PAH, cyanotic CHD, or complex CHD with residua such as heart failure, valve disease, or the need for anticoagulation.

Patients with cyanotic CHD, especially when associated with PAH, are at highest risk from noncardiac surgery (126). The bleeding risk can be reduced by preoperative phlebotomy if the hematocrit is more than 65% (127). Anesthetic management is critical, because a fall in systemic vascular resistance can worsen hypoxia, resulting in hemodynamic collapse. Long operations associated with hemodynamic instability and that require large-volume fluid replacement are associated with increased perioperative mortality. Fluid balance is critical in cyanotic and single-ventricle patients and those with heart failure because of occult renal failure in these patients.

Postoperatively, patients with CHD may need intensive care unit monitoring facilities even for relatively minor procedures. Nursing staff should be informed about the specific issues related to the CHD. Special issues that should be considered include administration of endocarditis prophylaxis, the need for anticoagulation around the time of the procedure, anticipation of special problems related to the underlying hemodynamics, filters for intravenous lines in cyanotic patients, prevention of venous thrombosis, monitoring of renal function, special care with drug administration, and the reduced arm blood pressure measurement in patients with prior classic Blalock-Taussig shunts. There is no evidence that cyanotic heart disease per se leads to liver disease (refer to Section 10, Tetralogy of Fallot, and Section 14, Tricuspid Atresia/Single Ventricle, for information regarding long-standing central venous hypertension leading to cardiac cirrhosis). There is increased prevalence of hepatitis C infection in adult patients who underwent CHD surgery before screening in 1992, and therefore these patients should be screened (128).

1.8. Recommendations for Pregnancy and Contraception

CLASS I

1. **Patients with CHD should have consultation with an ACHD expert before they plan to become pregnant to develop a plan for management of labor and the postpartum period that includes consideration of the appropriate response to potential complications. This care plan should be made available to all providers. (*Level of Evidence: C*)**
2. **Patients with intracardiac right-to-left shunting should have fastidious care of intravenous lines to avoid paradoxical air embolus. (*Level of Evidence: C*)**
3. **Prepregnancy counseling is recommended for women receiving chronic anticoagulation with warfarin to enable them to make an informed decision about maternal and fetal risks.** (129–131) **(*Level of Evidence: B*)**

CLASS IIa

1. **Meticulous prophylaxis for deep venous thrombosis, including early ambulation and compression stockings, can be useful for all patients with intracardiac right-to-left shunt. Subcutaneous heparin or low-molecular-weight heparin is reasonable for prolonged bed rest. Full anticoagulation can be useful for the high-risk patient. (*Level of Evidence: C*)**

CLASS III

1. The estrogen-containing oral contraceptive pill is not recommended for ACHD patients at risk of thromboembolism, such as those with cyanosis related to an intracardiac shunt, severe PAH, or Fontan repair. (*Level of Evidence: C*)

Congenital malformations now represent the most common cause of maternal morbidity and mortality from heart disease in North America. Better assessment and management of this group of patients is likely to make a substantial improvement in outcomes for mother and baby (132).

Both men and women with ACHD should have a thorough understanding of the risks of transmitting CHD to their offspring. Counseling by an ACHD expert before pregnancy is important and should include genetic evaluation and, specifically for women, assessment of potential fetal risk, risk of prematurity or low birth weight in the offspring, review of medications that may be deleterious to the fetus, appropriate management of anticoagulation, and discussion of potential maternal complications (132). If pregnancy occurs, fetal echocardiography should be obtained and its consequences discussed (132).

The outcome of pregnancy is favorable in most women with CHD provided that functional class and systemic ventricular function are good. PAH presents a serious risk during pregnancy, particularly when the pulmonary pressure exceeds 70% of systemic pressure, irrespective of functional class. Events often occur after delivery (133). The need for full anticoagulation during pregnancy, although not a contraindication, poses an increased risk to both mother and fetus (134). The relative risks and benefits of the different anticoagulant approaches need to be discussed fully with the prospective mother. There is a small group of patients with complex CHD or high-risk disorders in whom pregnancy is either dangerous or contraindicated owing to the risk to mother or fetus. If pregnancy occurs and continues with any of these disorders, these high-risk patients should be managed and delivered in specialized centers with multidisciplinary expertise and experience in CHD, obstetrics, anesthesiology, and neonatology. A coordinated care pathway for supervision of delivery and the postpartum period needs to be developed and in place by the third trimester and made available to all caregivers and to the patient. A normal vaginal delivery or an assisted delivery is usually feasible and may be preferable for patients with CHD. Cesarean delivery is recommended in patients with CHD for obstetric reasons and for women fully anticoagulated with warfarin at the time of delivery due to the risk of fetal intracranial hemorrhage.

Medications should be used only when necessary in any pregnant patient. Certain medications are contraindicated during pregnancy; these medications include angiotensin-converting enzyme (ACE) inhibitors and angiotensin receptor blockers. These medications cause congenital and renal disorders in the fetus when given during pregnancy; therefore, they should be discontinued before pregnancy occurs or early during pregnancy if possible (135). Warfarin should be used only after full discussion with the patient about the risks of using warfarin during pregnancy (136).

Although endocarditis is a recognized risk for maternal morbidity and mortality, endocarditis prophylaxis around the time of delivery is not universally recommended for patients with structural heart disease, because some believe that the risk of bacteremia is low. Others routinely administer antibiotics because it is not known in advance whether or not instrumentation will be required. Thus, there is no consensus on this point (117). Antibiotics should be considered for those at highest risk of an adverse outcome and, when appropriate, given as the membranes rupture. Intravenous amoxicillin and gentamicin should be considered for women with high-risk anatomy or previous history of endocarditis (see Section 1.6, Recommendations for Infective Endocarditis).

1.8.1. Contraception

It is the duty of the ACHD specialist to provide or otherwise make available informed advice on contraception, including discussion of risks. There are limited data on the safety of various contraceptive techniques in ACHD patients. The estrogen-containing oral contraceptive pill is generally not recommended in ACHD patients at risk of thromboembolism, such as those with cyanosis, prior Fontan procedure, atrial fibrillation, or PAH. In addition, this form of contraceptive therapy may upset anticoagulation control. However, medroxyprogesterone, the progesterone-only pills, and levonorgestrel may also cause fluid retention and should be used with caution in patients with heart failure. Depression and breakthrough bleeding may prevent the use of the progesterone-only pills, and there is a higher failure rate than with combined oral contraceptives.

Levonorgestrel, barrier methods, or tubal ligation are the recommended contraceptive methods for women with cyanotic CHD and PAH. The potential complications of the "morning after pill" (levonorgestrel "plan B") should be explained to those at risk of acute fluid retention. Tubal ligation, although the most secure method of contraception, can be a high-risk procedure in patients with complex CHD or those with PAH. Hysteroscopic sterilization (Essure) may be reasonable for high-risk patients (137). Sterilization of a male partner of a woman with CHD should only occur after full explanation of the prognosis to the patient. The specialist in the ACHD clinic needs to interact with both the general practitioner and the gynecologist to provide optimal advice regarding contraception. The risk of endocarditis with intrauterine devices in women with CHD is controversial, and recommendations should be individualized on the basis of discussions between the cardiologist and gynecologist.

Breast-feeding is safe in women with CHD. Women requiring cardiovascular medications should be aware that many of the medications will cross into breast milk and should clarify the potential effect of medications on the infant with a pediatrician.

1.9. Recommendations for Arrhythmia Diagnosis and Management

CLASS I

1. Complete and appropriate noninvasive testing, as well as clear knowledge of the specific anatomy and review of all surgical and procedural records, is recommended before electrophysio-

logical testing or device placement is attempted in ACHD patients. (*Level of Evidence: C*)

2. **Decisions regarding tachycardia management in ACHD patients should take into account the broad cardiovascular picture, particularly repairable hemodynamic issues that might favor a surgical or catheter-based approach to treatment. (*Level of Evidence: B*)**
3. **Catheter ablation procedures for ACHD patients should be performed at centers where the staff is experienced with the complex anatomy and distinctive arrhythmia substrates encountered in congenital heart defects. (*Level of Evidence: B*)**
4. **Pacemaker and device lead placement (or replacement) in ACHD patients should be performed at centers where the staff is familiar with the unusual anatomy of congenital heart defects and their surgical repair. (*Level of Evidence: B*)**
5. **Epicardial pacemaker and device lead placement should be performed in all cyanotic patients with intracardiac shunts who require devices. (*Level of Evidence: B*)**

CLASS IIa

1. **It is reasonable to recommend the use of an implantable cardioverter defibrillator for any patient who has had a cardiac arrest or experienced an episode of hemodynamically significant or sustained ventricular tachycardia (VT). (*Level of Evidence: C*)**
2. **Pacemaker implantation can be beneficial in ACHD patients with bradyarrhythmias and may be helpful in overdrive pacing in patients with difficult-to-control tachyarrhythmias (see ACC/AHA/HRS 2008 Guidelines for Device-Based therapy of Cardiac Rhythm Abnormalities). (138) (*Level of Evidence: B*)**

CLASS IIb

1. **Pacemaker implantation may be beneficial for asymptomatic adult patients with resting heart rates of less than 40 beats per minute or abrupt pauses in excess of 3 seconds. (*Level of Evidence: C*)**

Cardiac arrhythmias are a major source of morbidity and mortality for ACHD patients. Although rhythm disorders can often be observed in adults with unrepaired or palliated defects, the most difficult cases usually involve patients who have undergone prior intracardiac repairs, especially when this reparative surgery was performed relatively late in life (139,140). In this setting, the electrical pathology stems from the unique and complex myocardial substrates created by septal patches and suture lines in combination with cyanosis and abnormal pressure/volume status of variable duration. Virtually the entire spectrum of rhythm disturbances is manifested in these patients, including some disorders that are specific to the anatomic defect or the surgical technique used for repair (Table 8).

The optimal management strategy for many of these arrhythmias is as yet undetermined. The dramatic evolution of interventional electrophysiology in recent years, including techniques such as catheter or surgical ablation and implantation of antitachycardia devices, has broadened the list of therapeutic options significantly, but much of the literature in this field is still limited to small institutional series and anecdotal case reports. In the absence of large prospective outcome trials, current policies for arrhythmia treatment often involve extrapolation from studies of more conventional types of adult heart disease, such as ischemic myopathy. This approach, although a useful starting point, can underestimate the unique anatomic and physiological challenges of the ACHD patient. More organized multicenter research is needed in this area, as is more aggressive cross-training of electrophysiologists from both pediatrics and internal medicine to meet the special needs of these patients. Furthermore, until knowledge of these conditions is more widely disseminated, it is reasonable to recommend that interventional arrhythmia procedures be performed at centers where the staff is experienced with the complex anatomy and distinctive arrhythmia substrates encountered in congenital heart defects.

Table 8. Atrial Septal Defects and Associated Lesions

Type of Atrial Septal Defect	Associated Lesions
Secundum	• Pulmonic stenosis
	• Mitral valve prolapse
	• Partial anomalous pulmonary venous connection
Primum	• Cleft mitral valve
	• Discrete subaortic stenosis
Sinus venosus	• Partial anomalous pulmonary venous return
Coronary sinus	• Partial anomalous pulmonary venous return
	• Persistent left superior vena cava

1.9.1. Management of Tachyarrhythmias: Wolff-Parkinson-White Syndrome

Accessory pathways can complicate certain forms of CHD, especially Ebstein's anomaly of the tricuspid valve (141). Tachycardia symptoms may begin in childhood but become increasingly problematic in adult years, when atrial dilation or surgical scars predispose the patient to atrial flutter or atrial fibrillation with potential for rapid conduction over an accessory pathway. An attempt at definitive therapy with catheter ablation has become the standard of care for these patients. However, compared with simple accessory pathway ablation in a structurally normal heart, the acute success rates are reported to be lower and the risk of recurrence higher in patients with anatomic defects (141–143). These differences appear to relate to the challenges of distorted anatomic landmarks, abnormal location for the AV node, and a high incidence of multiple pathways in the CHD population. Intraoperative accessory pathway ablation can be considered in the patient with Ebstein's anomaly referred for operative intervention for tricuspid valve disease. This approach has been demonstrated to be safe and effective (144).

1.9.2. Intra-Atrial Reentrant Tachycardia or Atrial Flutter

The most common form of tachycardia seen in the ACHD patient population is macroreentry within atrial muscle. This arrhythmia usually surfaces as a late postoperative disorder, and in children, it has been associated with chronotropic incompetence. Although it may arise after nearly any procedure that involves a right atriotomy (even simple closure of an ASD), the incidence is clearly highest after the Mustard,

Senning, and Fontan operations, in which as many as 30% to 50% of patients can be expected to develop a symptomatic episode during extended follow-up (144,145). The term "intra-atrial reentrant tachycardia" (IART) has become the customary designation for this arrhythmia to distinguish it from classic atrial flutter seen in structurally normal hearts (146–148). Whereas typical atrial flutter involves a very predictable circuit around the tricuspid annulus that results in the familiar ECG appearance of sawtooth flutter waves at a rate of 300 beats per minute, IART can involve novel circuits around surgical scars and patches that generate a much wider spectrum of atrial rates and P-wave contours. Generally, IART tends to be slower than typical flutter, with atrial rates in the range of 170 to 250 beats per minute (144). In the setting of a healthy AV node, these rates will frequently allow a pattern of 1:1 AV conduction that may result in hemodynamic instability, syncope, or possibly death (149–151). Even if the ventricular response rate is safely titrated, sustained IART of long duration can be responsible for thromboembolic events.

Once IART is recognized, acute interruption is easily accomplished with either electrical cardioversion, overdrive pacing (150), or administration of certain class I or class III antiarrhythmic drugs (152). The far more difficult challenge is prevention of recurrence and adequate assessment of hemodynamic status that might predispose to recurrent tachycardia. Chronic antiarrhythmic drugs are still used in many cases, but the general experience with pharmacological therapy for this condition has been discouraging (149,153), which has led to a growing preference for nonpharmacological options at most centers.

Pacemaker implantation can be useful for those patients who have concomitant sinus node dysfunction as a prominent component of their clinical picture. Simply increasing the atrial rate to an appropriate level for the hemodynamic status can often result in marked reduction in IART frequency (150), while at the same time making it safer to prescribe medications that might aggravate bradycardia (138). Pacemakers with advanced programming features that incorporate atrial tachycardia detection and automatic burst pacing may also be beneficial in select cases (150,155) but carry the risk of accelerating the atrial rate and must thus be used cautiously in patients with robust AV conduction. Newer-generation implantable cardioverter defibrillators equipped with algorithms for both atrial tachycardia and VT detection and treatment, including atrial antitachycardia pacing and low-energy shocks for atrial tachycardia, have also been used successfully in a small number of ACHD patients with recurrent IART.

Catheter ablation has been adopted by many institutions as an early intervention for recurrent IART. The technique has evolved rapidly in terms of mapping accuracy and effectiveness, particularly since the introduction of 3-dimensional mapping technology for improved circuit localization (156,157) and irrigated-tip or large-tip ablation catheters for more effective lesion creation (158). With current technology, acute success rates of nearly 90% can be achieved with catheter ablation, although later tachycardia recurrence is still disappointingly common (159). The recurrence risk appears to be particularly high in the Fontan population of patients, who tend to have multiple IART circuits and the thickest/largest atrial dimensions. Although still far from perfect, ablation results for IART are likely to improve with continued advances in technology and even now are superior to the degree of control obtained with medications alone.

If the above measures fail to prevent IART recurrence, or if a patient with IART is returning to the operating room for hemodynamic reasons, consideration should be given to surgical ablation during a right atrial Maze operation. This procedure is used most commonly for the Fontan population with the most refractory variety of IART and is usually combined with revision of the Fontan connection or conversion from an older atriopulmonary anastomosis to a cavopulmonary connection. Results are encouraging, with very low rates of IART recurrence (160), but the surgical risks must be weighed against the electrophysiological benefit.

1.9.3. Atrial Fibrillation

Although far less common than IART in ACHD patients, atrial fibrillation is no less difficult to treat. It occurs most often in patients with congenital AS, mitral valve disease, or palliated single ventricles (161). Management principles are similar to atrial fibrillation encountered in other forms of heart disease, beginning with medical therapy for anticoagulation and ventricular rate control as needed, followed by electrical cardioversion. Class III antiarrhythmic agents may offer protection against recurrence of atrial fibrillation for some patients, but as in the case of IART, drug therapy has been only marginally successful for this group. Also similar to IART, pacemaker implantation may reduce atrial fibrillation episodes in patients with concomitant sinus node dysfunction. Successful elimination of atrial fibrillation has also been reported after combined right and left atrial Maze operations, which may be reasonable to consider if a patient requires cardiac surgery to address hemodynamic issues. Catheter ablation has not yet been extended in any systematic way to atrial fibrillation in the ACHD patient population.

1.9.4. Ventricular Tachycardia

There are several scenarios in which high-grade ventricular arrhythmias may develop in the ACHD patient. The most familiar involves macroreentrant VT as a late complication in postoperative patients who have undergone ventriculotomy and/or patching of a VSD, such as tetralogy of Fallot repair. In such cases, the reentry circuit is typically caused by narrow conduction corridors around regions of scar in the RV outflow tract (RVOT). The incidence of late VT or sudden death for repaired tetralogy has been estimated between 0.5% and 6.0% in various series (140,162,163). Some patients with slow organized VT may be hemodynamically stable at presentation, but VT tends to be rapid for the majority, producing syncope or cardiac arrest as the presenting symptom. The clinical picture is often confounded by the fact that symptomatic atrial tachycardias are also common in ACHD patients (164), which makes it difficult at times to tell whether an event was caused by VT, IART, or both.

Predicting which CHD patients will develop VT in advance of an episode remains a challenge. Studies seeking risk

factors in the population with tetralogy of Fallot have identified older age at time of reparative surgery, advanced degrees of RV dilation, and prolonged QRS duration greater than 180 milliseconds as independent variables (140,165–167), although the predictive accuracy for each of these factors is imperfect. Holter monitoring and exercise testing have also been examined as screening tools with some degree of correlation between spontaneous ectopy and future VT events, but because ectopy on ambulatory monitoring is nearly ubiquitous in this population, the positive predictive value is diluted. Formal ventricular stimulation study can discriminate between high- and low-risk CHD patients (168,169) but remains too imperfect and too impractical to be recommended as a general screening tool. Intracardiac electrophysiology testing is usually reserved for selected patients with concerning symptoms or Holter findings when VT is suspected but not yet proven. At present, there is no generally accepted scheme for rhythm surveillance in asymptomatic patients with tetralogy of Fallot. Some combination of the above tests must be viewed in the context of the individual patient's history and general hemodynamic status to guide testing and treatment decisions whenever symptoms are minimal or absent. Symptoms of palpitations, dizziness, or unexplained syncope would obviously heighten the index of suspicion and should trigger a thorough and prompt diagnostic evaluation, which probably should include formal electrophysiological testing.

Although tetralogy of Fallot is typically cited as the archetypal lesion when VT in the ACHD patient population is discussed, serious ventricular arrhythmias may also develop in a number of other malformations, even in the absence of direct surgical scarring to ventricular muscle. Examples include congenital AS, dextro- or levo-TGA when the right ventricle supports the systemic circulation, severe Ebstein's anomaly, certain forms of single ventricle, and VSD with PAH. The appearance of ventricular arrhythmias in these cases commonly coincides with deterioration in overall hemodynamic status (165).

Therapy for VT in ACHD patients is complex and evolving. Similar to VT treatment in ischemic heart disease, sole reliance on pharmacological management has now been largely abandoned. Empirical beta blockade and class I or class III agents might still be prescribed in rare cases when the clinician remains ambivalent about a patient's VT risk after thorough testing, but no data support this approach once sustained VT or cardiac arrest has occurred. Drug therapy has now been replaced at most centers by more definitive interventions, such as implantable cardioverter defibrillator placement, catheter ablation, or arrhythmia surgery. Before deciding among these options, hemodynamic catheterization combined with comprehensive electrophysiology study should be obtained. Reparable hemodynamic issues may be identified that would favor a surgical strategy for therapy, such as closure of a residual septal defect or relief of valve regurgitation, combined with intraoperative VT mapping and ablation (170). In addition, IART may be identified as either a contributing or confounding factor for a patient's symptoms and can be addressed with either catheter or surgical ablation at the same setting. Finally, if VT can be induced that is slow enough to support the circulation during mapping, catheter ablation of the VT circuit may be considered on the basis of the risks and benefits to the individual patient (171,172). Although reports of ablation for VT in ACHD patients are still limited to small series, it appears that it can be accomplished with a reasonable degree of acute success (173,174); however, the risk of VT recurrence after ablation is now being more clearly defined and may exceed 20% (174). It seems wise to reserve ablation as isolated VT therapy for those CHD patients with superior hemodynamics and single circuits of slow tachycardia, and even then, to perform follow-up stimulation studies to ensure that the same or different circuits cannot be induced before dismissing the need for an implantable cardioverter defibrillator. Perhaps a more important role for catheter ablation may be as supplemental therapy to reduce the shock burden in patients with frequent VT recurrences who already have an implantable cardioverter defibrillator in place.

Most ACHD patients with documented or highly suspected VT are now managed with an implantable cardioverter defibrillator (175). Transvenous systems are possible in most cases, with the notable exceptions of single-ventricle patients, those with obstructed venous channels, and those with significant intracardiac shunts who would be at risk for systemic embolic events from an intravascular lead. Acute defibrillation thresholds in CHD patients are comparable to those encountered in acquired heart disease. What may differ during follow-up is the need for lead revision. There is now growing evidence that lead failure from insulation or conductor breaks is relatively high in this group (175), which possibly reflects a more active lifestyle for young ACHD patients than for an older population with ischemic disease.

1.10. Management of Bradycardias

1.10.1. Sinoatrial Node Dysfunction

Although some rare forms of heterotaxy syndrome can be associated with congenital dysfunction or absence of the sinoatrial node, pathological sinus bradycardia in ACHD patients is more often an acquired problem related to cardiac surgery. Direct trauma to the sinoatrial node or its arterial supply occurs fairly frequently after the Mustard, Senning, Glenn, and Fontan operations (139,144,176,177). The likelihood of a patient developing IART or atrial fibrillation becomes significantly increased in this setting. Furthermore, patients with suboptimal hemodynamics may become symptomatic owing to chronotropic incompetence and the loss of AV synchrony. The updated guidelines for antibradycardia pacemaker implantation developed by the ACC and AHA (138) include information pertinent to CHD under the heading of "children and adolescents." These same guidelines can be applied reasonably well to ACHD patients. Implantation of an atrial or dual-chamber pacing system with activity responsiveness is recommended as a Class I indication in any symptomatic patient with sinoatrial node dysfunction. This will include most of those with tachy-brady syndrome and symptoms from recurrent atrial tachycardias, as well as any patient who is shown to have pause-dependent VT. Pacemaker implantation is also recommended as a Class IIb

indication for asymptomatic adult patients with resting heart rates of less than 40 beats per minute or abrupt pauses in excess of 3 seconds. The possibility of developing ventricular dysfunction with apical ventricular pacing exists. Although dual-chamber pacing systems may be implanted, manipulation of pacing programming to maintain atrial pacing with intact AV conduction is desirable.

There are a number of unique technical considerations during pacemaker implantation in ACHD patients. Transvenous lead positions, for example, will often have to be modified in response to the cardiac lesion and vascular redirection imposed by surgical patches or anastomotic stenosis, as occurs after the Mustard or Senning operations. Transvenous leads may be impossible or ill advised in other CHD lesions, including in some postoperative Fontan patients or patients with intracardiac shunting, thereby necessitating epicardial lead placement. With either the endocardial or epicardial approach, it can be challenging to locate lead anchor points with proper pacing and sensing function due to fibrosis and patching, particularly for an atrial lead. Clear knowledge of the specific anatomy and review of all surgical records are essential before device placement is attempted in these patients.

1.10.2. Atrioventricular Block

Surgical repair of CHD may result in direct trauma to the AV conduction tissues. Although improved knowledge of the anatomy of the AV node and His bundle in various CHD lesions has lessened its occurrence (178), closure of some VSDs, surgery for left-sided heart outflow obstruction, and replacement or repair of an AV valve may still be complicated by AV block. Fortunately, in more than half of cases, this injury is a transient phenomenon, and conduction recovers within 7 to 10 days of the operation (179). Permanent pacemaker implantation is advised (138) as a Class I indication for any patient with postoperative advanced second- or third-degree AV block that is not expected to resolve or persists at least 7 to 10 days after cardiac surgery. A pacemaker is also recommended by some as a Class IIb indication when surgical AV block recovers but the patient is left with permanent bifascicular block.

The AV conduction tissues may also be congenitally abnormal in terms of their location and function in specific forms of CHD, notably congenitally corrected TGA (CCTGA), as well as AV septal defect (AVSD), particularly those with Down syndrome (180–182). These patients may be more susceptible to surgical or catheter-induced AV block but may also develop AV block spontaneously at any point in time ranging from fetal life to adulthood. Patients with these particular anatomic defects merit periodic assessment of AV conduction with serial ECGs and Holter monitoring, even if AV conduction was not directly affected by surgery.

1.11. Cyanotic Congenital Heart Disease

Right-to-left intracardiac or extracardiac shunts result in hypoxemia, erythrocytosis, and cyanosis. Cyanotic ACHD patients should be seen at least annually by an ACHD specialist. Survival is determined by the type of underlying CHD and the medical complications of cyanosis.

1.11.1. Recommendations for Hematologic Problems

CLASS I

1. **Indications for therapeutic phlebotomy are hemoglobin greater than 20 g per dL and hematocrit greater than 65%, associated with headache, increasing fatigue, or other symptoms of hyperviscosity in the absence of dehydration or anemia. (*Level of Evidence: C*)**

CLASS III

1. **Repeated routine phlebotomies are not recommended because of the risk of iron depletion, decreased oxygen-carrying capacity, and stroke. (*Level of Evidence: C*)**

Cyanosis in patients with CHD has profound hematologic consequences that may affect many organ systems and need to be recognized and managed appropriately. The hematologic complications of chronic hypoxemia are erythrocytosis, iron deficiency, and bleeding diathesis (183). The increase in red blood cell mass that accompanies cyanosis is a compensatory response to improve oxygen transport. The white blood cell count is usually normal, and the platelet count may be normal or reduced.

The increased red blood cell mass may result in an increase in blood viscosity. However, the most likely cause of complications in adults with cyanotic CHD is aggressive phlebotomy or blood loss (184). Most cyanotic patients have compensated erythrocytosis with stable hemoglobin that requires no intervention. Therapeutic phlebotomy, therefore, is usually unnecessary unless the hemoglobin is more than 20 g/dL and the hematocrit is greater than 65% with associated symptoms of hyperviscosity and no evidence of dehydration. At these levels, patients may experience symptoms of headache and poor concentration. These symptoms may be relieved by removal of 1 unit of blood, always with an equal volume replacement of dextrose or saline. The purpose of the phlebotomy is to relieve hyperviscosity symptoms and occasionally, before elective operation, to improve coagulation. Repetitive phlebotomies deplete iron stores and may result in production of iron-deficient red blood cells. Iron deficiency, even in the face of erythrocytosis, is undesirable because of the reduced oxygen-carrying capacity and deformability of red blood cells (microcytes) and increased risk of stroke. A peripheral blood smear and serum ferritin or transferrin saturation will confirm the diagnosis.

The treatment for iron deficiency in a patient with destabilized erythropoiesis is challenging. Oral administration of iron frequently results in a rapid and dramatic increase in red cell mass; therefore, caution should be exercised and hemoglobin monitored. Once the serum ferritin and/or transferrin saturation is within the normal range, iron supplementation may be discontinued. Occasionally, patients are intolerant of oral iron and should be placed on pulses of intravenous iron supplementation instead.

1.11.1.1. Hemostasis

Hemostatic abnormalities have been documented in up to 20% of cyanotic patients. Platelet dysfunction and clotting

factor deficiencies combine to produce a bleeding tendency in these patients. Epistaxis, gingival bleeding, menorrhagia, and pulmonary hemorrhage are the most common causes of bleeding. The use of anticoagulants and antiplatelet agents, therefore, is controversial and confined to well-defined indications with careful monitoring of the degree of anticoagulation. For a given concentration of citrate solution, the volume must be adjusted downward to correct for the lower plasma volume in those with high hematocrits.

1.11.1.2. Renal Function

In chronic cyanosis, the renal glomeruli are abnormal, frequently hypercellular, and congested and eventually become sclerotic (185). This results in a reduction of the glomerular filtration rate, increased creatinine levels, and proteinuria. This may cause problems with radiopaque contrast material and dehydration, leading to uremia, oliguria, and even anuria. Thus, patients should be hydrated before procedures that involve contrast media.

Abnormal urate clearance is common, and this in conjunction with an increased turnover of red blood cells leads to hyperuricemia and occasionally gout. Hyperuricemia without gout is usually well tolerated and rarely requires intervention (186). Symptomatic gout should be treated.

Medications that affect renal function, such as ACE inhibitors, diuretics, nonsteroidal antiinflammatory drugs, and select antibiotics, should be given with concern and cautious monitoring. As in all persons proceeding to catheterization, cyanotic patients should have an appropriate assessment of glomerular filtration rate (which may require more than measurement of serum creatinine), and the hydration state should be maximized within the constraints of appropriateness for a safe procedure. A low threshold for the use of renally protective strategies (*N*-acetylcysteine or bicarbonate administration) should be considered when indicated.

1.11.1.3. Gallstones

The increased breakdown of red blood cells in chronic cyanosis results in an increased risk of calcium bilirubinate gallstones. Surgical intervention is not recommended until patients become symptomatic (refer to Section 1.7, Recommendations for Noncardiac Surgery).

1.11.1.4. Orthopedic and Rheumatologic Complications

Hypertrophic osteoarthropathy with thickened, irregular periosteum occurs in the setting of cyanotic CHD. This may be accompanied by aching and tenderness, especially in the long bones of the legs.

Scoliosis occurs in a high percentage of patients with cyanotic CHD and is occasionally severe enough to compromise pulmonary function and require surgical intervention. Preoperative evaluation by an ACHD cardiologist and cardiac anesthesiologist is recommended before the operation for scoliosis is undertaken because of the recognized increased risk of surgery in cyanotic patients, especially those with PAH, for which this procedure may be contraindicated.

1.11.1.5. Neurological Complications

Neurological complications include an increased risk for paradoxical cerebral emboli. Brain abscess in cyanotic patients and thromboembolic events in patients with atrial tachycardia or atrial stasis associated with transvenous pacing leads can result in new neurological symptoms. These complications should be suspected in a cyanotic patient with headache, fever, and new neurological symptoms. Substantial cognitive and psychosocial issues are prevalent in this population, as discussed in Section 1.5.2, Recommendations for Psychosocial Issues.

1.11.1.6. Pulmonary Vascular Disease

Pulmonary vascular disease commonly accompanies cyanosis in patients with ACHD. The management of and concerns about pulmonary vascular disease and ACHD are discussed in more detail in a later section (Section 9, Pulmonary Hypertension/Eisenmenger Physiology).

1.12. Recommendations for General Health Issues for Cyanotic Patients

CLASS I

1. **Cyanotic patients should drink nonalcoholic and noncaffeinated fluids frequently on long-distance flights to avoid dehydration. (*Level of Evidence: C*)**

CLASS IIb

1. **Supplemental oxygenation may be considered for cyanotic patients during long-distance flights. (*Level of Evidence: C*)**

Cyanotic patients should use only pressurized commercial airplanes. Oxygen therapy, although often unnecessary, may be suggested for prolonged travel. Similarly, residence at high altitude is detrimental for patients with cyanosis. Dehydration should be avoided by frequent fluid intake on long flights and during sports activities.

Competitive sports should be avoided in cyanotic patients (187). Cyanosis is a recognized handicap to fetal growth and development, and pregnancy outcome is impacted, with an increased risk of congestive heart failure, preterm delivery, intrauterine growth retardation, and miscarriage. Increased maternal and fetal mortality are also noted and correlate with the degree of cyanosis, ventricular dysfunction, and pulmonary pressures (117).

1.12.1. Hospitalization and Operation

Cyanotic patients are at high risk during any hospitalization or operation. When hospitalized for medical or surgical problems, these patients should be seen and followed up by an ACHD specialist. Management strategies that should be applied include those likely to reduce the risk of paradoxical emboli related to air in the intravenous lines. Medication adjustment may be needed, with cyanosis taken into account. Early ambulation may prevent venous stasis and thrombophlebitis.

1.12.2. Cardiac Reoperation and Preoperative Evaluation

Although some ACHD patients present without prior intervention, the majority will have undergone 1 or more prior repairs. Review of prior operative notes can provide important insight when a cardiac repair is planned. Repeat sternotomy may be associated with cardiac injury. The heart and

great arteries may be closely adherent to the sternum because of the loss of pericardial integrity or presence of conduit material in the anterior mediastinum. In addition, right-sided heart structures may be enlarged or hypertensive, which also increases the potential for injury during sternotomy. Morphological abnormalities of the aorta, pulmonary artery, or ventricle–to–pulmonary artery conduit may also be at increased risk of injury. Peripheral vascular abnormalities may be present secondary to previous cardiac catheterization or operative procedures. For example, the radial pulse may be absent in patients with a prior classic Blalock-Taussig shunt. Femoral artery or vein occlusion may have occurred secondary to prior catheterization procedures or indwelling monitoring lines. Knowledge of the status of femoral or auxiliary vessels before reoperation may be particularly important if cannulation for establishment of cardiopulmonary bypass via these vessels is being planned.

To minimize the potential problems that may arise at the time of rerepair, additional preoperative studies may be necessary. The choice of the various supplemental imaging studies should be individualized on the basis of the surgeon's preference and institutional availability. Imaging studies that are frequently used include ultrasound, cine angiography, or MRI to document patency of cardiac anatomy (or occlusion) and status of femoral or axillary vessels. Coronary angiography or CT angiography is used to identify coronary anomalies or obstructive lesions. CT imaging of the chest may be helpful in identifying the relationship and proximity of the right ventricle, right atrium, aorta, pulmonary artery, or extracardiac conduit to the sternum or anterior chest wall. The importance of reviewing prior surgical notes when a repeat operation is planned cannot be overemphasized.

Men aged 35 years or older, premenopausal women 35 years or older with risk factors for atherosclerosis, and postmenopausal women should be evaluated by cardiac catheterization and coronary angiography to rule out associated coronary artery disease before they undergo reoperative cardiac surgery (112).

1.13. Heart Failure in Adult Congenital Heart Disease

The New York Heart Association classification may be inadequate in ACHD patients, particularly if they are cyanotic. Respiratory physiology in cyanotic heart disease is well understood, and it is known that dyspnea may occur within the first 30 seconds of commencing exercise because of the arrival of hypoxemic and acidotic blood at the central receptors; thus, such dyspnea is not due to "pulmonary congestion," as is the case in heart failure (188–190). Therefore, cyanotic patients with ACHD may have dyspnea on exertion without having heart failure. It is preferable to use a functional ability or activity index (191). The patient with CHD who survives to adulthood will often have 1 or more substrates for developing the clinical syndrome of heart failure, which may either be right- or left-sided or involve both sides of the circulation. Typical ACHD substrates for late heart failure in ACHD patients are as follows:

- Severe AS and/or regurgitation BAV and variants, subvalvular or supravalvular pathology, superimposed coarctation
- Severe congenital mitral stenosis/regurgitation
- Unoperated ASD or partial AVSD
- CCTGA
- D-transposition after Mustard or Senning operation, in which the morphological right ventricle is the systemic ventricle
- Tetralogy of Fallot with early-era surgery, long-standing shunt, or severe pulmonary regurgitation
- Single-ventricle physiology
- Fontan surgery.

Many ACHD patients have experienced a combination of prolonged volume and pressure overload. Factors that predispose to the development of late heart failure include abnormal anatomy, surgical sequelae, and progression of underlying pathology. Myocardial damage during cardiac surgery was more common in patients who had operations during the earlier surgical era, but it may still occur in the present day with long cardiopulmonary bypass time, the need for large patches, or incisional scars (192). The reason for late heart failure in certain subsets of ACHD patients is of intense interest but not completely resolved. For example, anomalies in which the SV is a morphological right ventricle or there is a single ventricle have a higher incidence of myocardial dysfunction over time and with time may develop heart failure pathology (193). The presence of significant tricuspid (especially systemic AV valve) regurgitation is strongly associated with RV dysfunction and may be progressive (194). Inappropriate ventricular hypertrophy or myocardial oxygen supply-demand imbalance that results in myocardial ischemia has also been proposed to be a causative factor (195,196). In some forms of cardiac failure, there is evidence of biventricular interaction such that dysfunction of either ventricle negatively influences the other (ie, ventricular-ventricular dependence) (197,198). A straightforward example of adverse interventricular interaction is seen in right-sided heart volume overload in ASD, which results in changes in left ventricular (LV) shape, end-diastolic volume, and ejection fraction, which will normalize after closure of the defect (197). A recent special report on ventricular form and function, although targeted at the left ventricle, notes a shift from primary emphasis on contractile state and load to newer concepts of interaction and dynamic rearrangement of the myocardial layers, factors that may be altered considerably in CHD (199,200). To these substrates, other possible pathogenetic factors for heart failure can be added, such as the following:

- Prolonged cyanosis
- Prolonged pressure overload (eg, AS and subaortic stenosis [SubAS])
- Prolonged volume overload (eg, aortopulmonary shunt, AV semilunar valve regurgitation, or residual shunt)
- Poor myocardial intraoperative preservation
- Large ventricular septal patch
- Large ventricular incisions/scar
- Residual LVOT or RVOT obstruction (eg, PS/pulmonary regurgitation) or shunts (eg, VSD patch leak)

- Arrhythmias
- Obesity.

In addition, the following superimposed diseases or conditions unrelated to ACHD patients that become common in adulthood can contribute to or "tip the balance" toward development of heart failure:

- Acquired valvular heart disease
- Coronary artery disease
- Systemic hypertension
- Diabetes mellitus
- Pregnancy
- Endocarditis
- Chronic respiratory disease
- Cardiotoxic chemotherapy/mediastinal irradiation
- Illicit drug use
- Acquired renal or liver disease
- Obstructive sleep apnea
- Hyperthyroidism or hypothyroidism.

One concept that deserves more attention in the field of heart failure and ACHD is that of "ventriculoarterial coupling." It is well known that increased systemic arterial pressure or isolated systolic hypertension occurs in many individuals as they age and that this has detrimental effects. Changes in aortic diameter, stiffness, and wave reflection increase with age, which leads to an increase in ventricular afterload and may adversely affect late systolic ejection and/or early diastolic relaxation. Such aging changes may be detrimental to a systemic right or single ventricle that is ill prepared for any additional afterload. In addition, a combination of ventricular hypertrophy and arterial stiffening may lead to diastolic heart failure in the presence of preserved ventricular ejection fraction.

Signs of heart failure in ACHD patients may vary from the usual findings in patients with acquired heart disease and heart failure. Cardiorespiratory and ventilatory responses to exercise after a Fontan procedure, for example, are subnormal, including lower than expected $\dot{V}o_2$ max, subnormal cardiac output and heart rate responses to exercise, and an abnormal reduction of resting arterial O_2 saturation at peak exercise. After a Fontan or Glenn procedure, interpretation of the jugular venous pressure loses its usual meaning.

The ACC/AHA 2005 Guideline Update for the Diagnosis and Management of Chronic Heart Failure in the adult appropriately notes that critical assessment of ventricular function is needed in the patient with heart failure (201). It is desirable that assessments of function include quantitative measurements (eg, cardiopulmonary exercise testing with determination of oxygen consumption or cardiac function assessed by echocardiography with specific measures of systolic and diastolic function). Cardiac MRI to assess ventricular anatomy and function, dimensions, myocardial perfusion, and ischemia in adults with unoperated or operated CHD (eg, after atrial switch procedures) may be helpful (202–204). MRI studies of systemic right ventricles and single ventricles may show abnormalities of myocardial twist, torsion, radial motion, shortening, and strain relations (205,206). The frequent presence of abnormal ventricular anatomy warrants the addition of a Doppler echocardiography–derived index of myocardial performance index (or Tei index) or measurement of blood levels of brain natriuretic peptide (BNP) (192–194,207,208).

BNP production is affected by ventricular wall stress (eg, pressure overload such as AS, in which BNP appears to be influenced by both systolic and diastolic load) (209). BNP has been shown to be elevated not only in patients with heart failure and LV systolic dysfunction but also in patients with diastolic dysfunction and in RV dysfunction (198). However, BNP can be elevated in cyanotic heart disease without evidence of heart failure or myocardial dysfunction (210). BNP levels overall have been shown to be predictors of cardiac events (211) and have been shown to aid in emergency department diagnosis of heart failure when the cause of a patient's dyspnea is unclear (212), but their role in outpatient diagnosis and clinical follow-up of heart failure and ACHD remains under investigation. Serial measurement of BNP in patients at risk for the development of heart failure, such as patients with single-ventricle anatomy, may prove useful in guiding intervention.

Many current therapeutic strategies for the treatment of heart failure are directed at blocking activation of the neurohormonal system. The role of such medical treatments (eg, ACE inhibitors, angiotensin receptor blockers, and beta blockers) in the prevention or treatment of heart failure has only been studied in small numbers of ACHD patients. One such report on the use of ACE inhibitors in adults after the Mustard procedure showed no significant change in MRI parameters of RV volumes and ejection fractions or of measured exercise capacity ($\dot{V}o_2$ max, exercise duration, and blood pressure response) for the group as a whole, although there was improvement in some patients; the authors recommended a multiinstitutional prospective trial (53).

Established medical therapy for those with acquired heart disease and heart failure now incorporates medications directed at the renin-angiotensin-aldosterone system and sympathetic nervous systems. Although there exist multiple large, randomized, controlled clinical trials of drugs and other therapeutic interventions for heart failure in acquired heart disease, none have included the ACHD population (213). Thus, one should extrapolate cautiously from heart failure trials in acquired heart disease (214–218).

Aldosterone blockade with spironolactone has been shown in a small number of Fontan patients to improve the protein-losing enteropathy (PLE) syndrome (219). Few clinical trials have addressed the effect of angiotensin receptor blockers on outcomes in any adult patients with CHD. The role of the central and peripheral autonomic nervous system in ACHD patients has received some attention but needs further investigation (220–226). For example, in patients with previously operated tetralogy of Fallot, RVOT reconstruction may have affected cardiac autonomic nervous activity, which may also affect exercise hemodynamics, in part via heart rate recovery, altered respiratory physiology, and a decreased systolic blood pressure response with reduced cardiac output reserve. Critical investigation of various medications and other interventions for the possible treatment or prevention of heart failure in patients after tetralogy of Fallot repair, in patients with diminished systemic

right or single-ventricle function, and in patients after a Fontan procedure is needed to optimize outcomes for these patients.

The role of pacemaker therapy in the treatment of cardiac failure is evolving rapidly (71,227). The need for pacing often coincides with worsening hemodynamic status, and it is not always possible to separate cause and effect. Regardless, it is well known that abnormal activation sequences (eg, from RV pacing) may cause a reduction in ventricular function (228,229).

Intraventricular or interventricular dyssynchrony may exacerbate chronic heart failure. Cardiac resynchronization therapy is an accepted means of improving ventricular function in conditions with normal 2-ventricle morphology and is now being proposed for treatment of heart failure in patients with a systemic RV (230). At present, there is no evidence to support its use in any patient with single-ventricle morphology. Current criteria for cardiac resynchronization therapy implantation in patients with normal (2-ventricle) morphology and heart failure include persistent heart failure symptoms despite appropriate medical therapy, QRS duration greater than or equal to 120 milliseconds with left bundle-branch block morphology, and the presence of sinus rhythm.

1.14. Recommendations for Heart and Heart/Lung Transplantation

CLASS I

1. **Patients with CHD and heart failure who may require heart transplantation should be evaluated and managed in tertiary care centers with medical and surgical personnel with experience and expertise in the management of both CHD and heart transplantation. (*Level of Evidence: C*)**
2. **Patients with CHD and heart or respiratory failure who may require lung or heart/lung transplantation should be evaluated and managed in tertiary care centers with medical and surgical personnel with experience and expertise in the management of CHD and lung or heart/lung transplantation. (*Level of Evidence: C*)**

In ACHD patients, postoperative ventricular failure may occur early after operation but more commonly develops late after operation, often in adulthood. Late systemic ventricular failure can be associated with many congenital diagnoses.

The pretransplantation evaluation involves a multidisciplinary approach that addresses assessment of cardiopulmonary, renal, neurological, hepatic, infectious disease, socioeconomic, and psychological issues. In addition to history and physical examination, diagnostic studies include ECG, echocardiography, chest x-ray, and Holter monitoring. Cardiac catheterization is required to assess pulmonary vascular resistance (PVR) and transpulmonary gradient (231). In addition to cardiac catheterization, MRI or CT angiography is often performed to delineate the anatomy in patients with complex CHD (eg, patients with malposition of the great arteries and/or substernal position of an extracardiac conduit, abnormalities of systemic venous return, and situs abnormalities).

Many patients with long-standing heart failure may have elevated PVR. Consequently, donor right-sided heart failure may result when the heart is abruptly placed proximal to such a high-resistance pulmonary vascular bed. Pharmacological modulation of pulmonary hemodynamics with pulmonary vasodilators during cardiac catheterization helps predict outcome after heart transplantation (232,233). In most centers, a fixed PVR index of 6 units or more or a transpulmonary gradient greater than 15 mm Hg that does not respond to vasodilator therapy (oxygen, nitric oxide, milrinone, or dobutamine) is a contraindication to cardiac transplantation alone, although transplantation from a rare donor with PAH in a Domino procedure with heart/lung transplantation in 1 recipient followed by transplantation of the recipient's heart into another recipient may still be successful.

Contraindications to cardiac transplantation include the following:

- Active infection
- Positive serology for human immunodeficiency virus or hepatitis C infections
- Severe metabolic disease
- Multiple other severe congenital anomalies
- Multisystem organ failure
- Active malignancy
- Cognitive or behavioral disability that interferes with compliance.

Heart/lung transplantation is usually reserved for patients with uncorrectable or previously repaired or palliated CHD associated with significant pulmonary vascular obstructive disease, such as single-ventricle physiology with pulmonary vascular disease or LV dysfunction with associated pulmonary vascular disease. When a simple cardiac defect is present, such as ASD, VSD, or PDA, the cardiac defect can often be repaired at lung transplantation (234). In the presence of more complex intracardiac abnormalities, combined heart/lung transplantation is usually most appropriate.

Previous thoracotomies are not an absolute contraindication to transplantation, but in the presence of chronic cyanosis, vascular collaterals may lead to fatal hemorrhagic complications. The absence of detectable recurrence of malignancy for 5 years may permit successful transplantation. Obesity is a relative contraindication to transplantation.

Survival rates after heart transplantation have improved over the years, and the current predicted posttransplantation half-life (the time at which 50% of those with transplanted organs remain alive, or median survival) for the entire cohort of pediatric and adult heart recipients is 10 years, with a half-life of 13 years for those who survive the first year; however, having ACHD as an indication for transplant increases that risk during the first year by 2-fold (235).

Advances in selection, technique, and management of patients undergoing lung or heart/lung transplant have resulted in significant improvement in survival. Overall, survival after pediatric lung transplantation as reported by the International Society of Heart and Lung Transplant registry is approximately 75% at 1 year and 60% at 2 years (236). The most common cause of mortality in the first month after lung transplantation is acute graft failure; from 1 month to 1 year after transplantation, infection is the

leading cause of death. From 1 to 3 years after lung transplantation, chronic rejection or bronchiolitis obliterans is the leading cause of death. Beyond this time frame, main causes of death include chronic rejection and infection. The outcome for heart/lung transplantation is similar to that for lung transplantation.

Actuarial survival at 10 years after heart/lung transplantation is 20%. Results of lung and heart/lung transplantation for PAH and ACHD are comparable to those reported for children, with an increased risk of early mortality related to perioperative complications and complexity compared with transplantation for obstructive pulmonary disease or cystic fibrosis. Outcomes for lung transplantation and cardiac repair are comparable to those for heart/lung transplantation in the treatment of PAH and CHD (237).

2. Atrial Septal Defect

2.1. Definition

One of the most common adult congenital heart defects, an ASD is a persistent communication between the atria. There are several different types of ASD: the secundum ASD in the region of the fossa ovalis (75% of cases), the primum ASD (15% to 20%) positioned inferiorly near the crux of the heart, the sinus venosus ASD (5% to 10%) located superiorly near the superior vena caval entry or inferiorly near the inferior vena caval entry, and the uncommon coronary sinus septal defect (less than 1%), which causes shunting through the ostium of the coronary sinus (238). The patent foramen ovale (PFO) is a flaplike communication in which the septum primum covering the fossa ovalis overlaps the superior limbic band of the septum secundum. In some patients, the septum primum or secundum is aneurysmal and may have multiple small fenestrations.

2.1.1. Associated Lesions

ASD can be associated with additional malformations in nearly 30% of cases (Table 9) (239). As a form of AVSD, the primum ASD is nearly always accompanied by a cleft in the anterior mitral valve leaflet. Discrete SubAS may develop postoperatively. Sinus venosus defects frequently have partial anomalous venous drainage of the right pulmonary veins. This association is present in a small number of patients with secundum ASDs as well. Mitral valve prolapse is frequently seen in patients with ASD. Valvular pulmonic stenosis is frequently described in association with ASD, but in some cases, there is a mild RV outflow gradient that is caused by increased flow but not a structural valve abnormality (240,241).

Coronary sinus septal defect, a defect in the roof of the coronary sinus and not technically an ASD, may be accompanied by partial or total anomalous pulmonary venous connection and/or a persistent left superior vena cava draining to the coronary sinus.

2.2. Clinical Course

2.2.1. Unrepaired Atrial Septal Defect

The consequence of left-to-right shunt across an ASD is RV volume overload and pulmonary overcirculation. Large atrial shunts lead to symptoms from excess pulmonary blood flow and right-sided heart failure, including frequent pulmonary infections, fatigue, exercise intolerance, and palpitations. Atrial arrhythmias—atrial flutter, atrial fibrillation, and sick sinus syndrome—are a common result of long-standing right-sided heart volume and pressure overload. Flow-related PAH accompanies large left-to-right shunts, and pulmonary vascular obstructive disease may develop in adult years but occurs much later with ASD than with high-pressure left-to-right shunts such as VSD or PDA. Paradoxical embolism from peripheral venous or pelvic vein thromboses, atrial arrhythmias, unfiltered intravenous infusions, or indwelling venous catheters is a risk for all defects regardless of size (242–244).

The initial presentation in adulthood most commonly includes symptoms of dyspnea and palpitations (245,246). Other modes of presentation in the previously undiagnosed adult with an ASD include cardiomegaly on routine chest x-ray, a more audible murmur during pregnancy, new onset of atrial flutter/fibrillation, or a paradoxical embolic event.

Table 9. Rhythm Disturbances in Adults With Congenital Heart Disease

Rhythm Disturbance	Associated Lesions
Tachycardias	
Wolff-Parkinson-White syndrome	Ebstein's anomaly
	Congenitally corrected transposition
Intra-atrial reentrant tachycardia (atrial flutter)	Postoperative Mustard
	Postoperative Senning
	Postoperative Fontan
	Tetralogy of Fallot
	Other
Atrial fibrillation	Mitral valve disease
	Aortic stenosis
	Tetralogy of Fallot
	Palliated single ventricle
Ventricular tachycardia	Tetralogy of Fallot
	Aortic stenosis
	Other
Bradycardias	
Sinus node dysfunction	Postoperative Mustard
	Postoperative Senning
	Postoperative Fontan
	Sinus venosus ASD
	Heterotaxy syndrome
Spontaneous AV block	AV septal defects
	Congenitally corrected transposition
Surgically induced AV block	VSD closure
	Subaortic stenosis relief
	AV valve replacement

AV indicates atrioventricular; ASD, atrial septal defect; and VSD, ventricular septal defect.

Patients with small defects (less than 10 mm) may remain asymptomatic well into the fourth and fifth decade of life (236,246); however, symptoms may develop with increasing age even with small defects owing to an increase in shunting caused by a decrease in LV compliance secondary to coronary artery disease, acquired valvular disease, or hypertension.

2.3. Recommendations for Evaluation of the Unoperated Patient

CLASS I

1. **ASD should be diagnosed by imaging techniques with demonstration of shunting across the defect and evidence of RV volume overload and any associated anomalies. (*Level of Evidence: C*)**
2. **Patients with unexplained RV volume overload should be referred to an ACHD center for further diagnostic studies to rule out obscure ASD, partial anomalous venous connection, or coronary sinoseptal defect. (*Level of Evidence: C*)**

CLASS IIa

1. **Maximal exercise testing can be useful to document exercise capacity in patients with symptoms that are discrepant with clinical findings or to document changes in oxygen saturation in patients with mild or moderate PAH. (*Level of Evidence: C*)**
2. **Cardiac catheterization can be useful to rule out concomitant coronary artery disease in patients at risk because of age or other factors. (*Level of Evidence: B*)**

CLASS III

1. **In younger patients with uncomplicated ASD for whom imaging results are adequate, diagnostic cardiac catheterization is not indicated. (*Level of Evidence: B*)**
2. **Maximal exercise testing is not recommended in ASD with severe PAH. (*Level of Evidence: B*)**

The diagnostic workup for a patient with a suspected ASD is directed at defining the presence, size, and location of the ASD; the functional effect of the shunt on the right and left ventricles and the pulmonary circulation; and any associated lesions.

2.3.1. Clinical Examination

Clinical findings include a precordial lift, systolic pulmonary flow murmur, and fixed splitting of the second heart sound (although fixed splitting is not invariable). With large shunts, a diastolic flow rumble across the tricuspid valve is present.

2.3.2. Electrocardiogram

The ECG often shows right-axis deviation, right atrial enlargement, incomplete right bundle-branch block (secundum ASD), superior left-axis deviation (primum ASD), or an abnormal P-wave axis (superiorly located sinus venosus ASD). Complete heart block may be present in association with familial ASD (247). The superior left axis with RV conduction delay seen in primum ASD is due to the anatomic position of the conduction bundles and should not be confused with bifascicular block.

2.3.3. Chest X-Ray

The chest x-ray may show RV and right atrial enlargement, a prominent pulmonary artery segment, and increased pulmonary vascularity.

2.3.4. Echocardiography

A TTE is the primary diagnostic imaging modality for ASD. The study should include 2-dimensional imaging of the atrial septum from the parasternal, apical, and subcostal views with color Doppler demonstration of shunting. Subcostal views with deep inspiration and high right parasternal views can be particularly helpful for imaging ASD in adults. The entire atrial septum from the orifice of the superior vena cava to the orifice of the inferior vena cava should be visualized to detect sinus venosus defects or the extension of large secundum defects in these regions. A TEE may be necessary to identify the connection of all pulmonary veins in patients with ASD. In adults with poor-quality transthoracic images, TEE may be necessary to adequately image the atrial septum (248–251), because it provides exact localization and sizing of the ASD, as well as measurement of septal rims, each of which is important for decision making.

A large coronary sinus orifice with evidence of atrial shunting may indicate a defect in the roof of the coronary sinus (eg, sinoseptal defects). Thus, the entire coronary sinus roof should be imaged when this is suspected. When a coronary sinoseptal defect is associated with lesions that cause right-to-left shunting, the orifice of the coronary sinus may not be enlarged and the defect not recognized until after definitive surgery, at which time a left-to-right shunt may occur. With PAH, the low velocity of the shunt flow across the coronary sinoseptal defect may be difficult to distinguish from other low-velocity flow within the atria.

Right atrial and RV enlargement with diastolic flattening and paradoxical motion of the interventricular septum are evidence of RV volume overload and a significant left-to-right shunt. The RV systolic pressure should be estimated from the peak velocity of the tricuspid regurgitant jet if present. Two-dimensional imaging should assess associated lesions such as mitral valve prolapse, cleft mitral valve, anomalous pulmonary veins, and PS, and their functional significance should be determined by color and spectral Doppler.

Contrast echocardiography with intravenous agitated saline injection is used to confirm the presence of a right-to-left atrial shunt if imaging and color Doppler are not conclusive (252). Additionally, the presence of negative contrast in the right atrium may be helpful in identifying a left-to-right shunt. If a left-to-right shunt or RV volume overload is recognized but unexplained, the patient should be referred to an ACHD center for further imaging studies.

2.3.5. Magnetic Resonance Imaging

MRI provides an additional noninvasive imaging modality if findings by echocardiography are uncertain. Direct visualization of the defect and pulmonary veins is possible, RV volume and function can be quantified, and estimates of shunt size can also be obtained (253–255). Contrast-enhanced ultrafast cine CT can also provide diagnostic information,

although the radiation exposure limits its utility in most cases (256).

Diagnostic cardiac catheterization is not required for uncomplicated ASDs in younger patients with adequate noninvasive imaging (257,258). It is generally reserved for investigation of coronary artery disease in those patients at risk by virtue of age or family history and for whom surgical intervention is planned and to assess PVR and reactivity in patients with significant PAH. Catheterization may also be required to evaluate ASD size, pulmonary venous return, and associated valvular disease if noninvasive methods have been unable to provide this information. In most instances, catheterization is now performed in conjunction with device closure of the defect.

2.3.6. Exercise Testing

Exercise testing can be useful to document exercise capacity in patients with symptoms that are discrepant with clinical findings or to document changes in oxygen saturation in patients with PAH. Maximal exercise testing is not recommended in ASD with severe PAH, however.

2.4. Diagnostic Problems and Pitfalls

The gradual onset of symptoms and the subtlety of the physical findings with ASDs often lead to late diagnosis, which puts the patient at greater risk for developing PAH, arrhythmia, and paradoxical embolism. False-positive diagnosis of ASD can result from either apparent septal dropout on 2-dimensional echocardiography images or misinterpretation by color Doppler of vena caval inflow as shunt flow. The use of contrast echocardiography or TEE will prevent false-positive interpretations. Patients with partial anomalous pulmonary venous drainage without an ASD will have RV volume overload and may be erroneously presumed to have an ASD.

False-negative diagnoses are relatively common in adults with poor-quality transthoracic images, especially patients with sinus venosus ASD. Because of its superior location, the superior sinus venosus defect is most often missed by TTE (248). Patients with an unexplained RV volume overload by TTE should be studied by TEE or another imaging modality to fully evaluate the atrial septum and pulmonary veins and to rule out defects in the roof of the coronary sinus.

2.5. Management Strategies

2.5.1. Recommendations for Medical Therapy

CLASS I

1. **Cardioversion after appropriate anticoagulation is recommended to attempt restoration of the sinus rhythm if atrial fibrillation occurs. (*Level of Evidence: A*)**
2. **Rate control and anticoagulation are recommended if sinus rhythm cannot be maintained by medical or interventional means. (*Level of Evidence: A*)**

Patients with small shunts and normal RV size are generally asymptomatic and require no medical therapy. Routine follow-up of the patient with a small ASD without evidence of RV enlargement or PAH should include assessment of symptoms, especially arrhythmias, and possible paradoxical embolic events. A repeat echocardiogram should be obtained every 2 to 3 years to assess RV size and function and pulmonary pressure. Reductions in LV compliance related to hypertension, coronary artery disease, or acquired valvular disease increase the degree of left-to-right shunt across an existing ASD.

Atrial arrhythmias should be treated to restore and maintain sinus rhythm if possible (259). If atrial fibrillation occurs, both antiarrhythmic therapy and anticoagulation should be recommended.

ASDs that are large enough to cause PAH should be closed provided there is evidence of pulmonary vascular reactivity and a net left-to-right shunt. Medical therapy for PAH is indicated only for those patients who are considered to have irreversible PAH and therefore are not eligible for ASD closure (refer to Section 9, Pulmonary Hypertension/Eisenmenger Physiology, for more extensive discussion of the treatment of PAH).

2.5.2. Recommendations for Interventional and Surgical Therapy

CLASS I

1. **Closure of an ASD either percutaneously or surgically is indicated for right atrial and RV enlargement with or without symptoms. (*Level of Evidence: B*)**
2. **A sinus venosus, coronary sinus, or primum ASD should be repaired surgically rather than by percutaneous closure. (*Level of Evidence: B*)**
3. **Surgeons with training and expertise in CHD should perform operations for various ASD closures. (*Level of Evidence: C*)**

CLASS IIa

1. **Surgical closure of secundum ASD is reasonable when concomitant surgical repair/replacement of a tricuspid valve is considered or when the anatomy of the defect precludes the use of a percutaneous device. (*Level of Evidence: C*)**
2. **Closure of an ASD, either percutaneously or surgically, is reasonable in the presence of:**
   a. **Paradoxical embolism. (*Level of Evidence: C*)**
   b. **Documented orthodeoxia-platypnea. (*Level of Evidence: B*)**

CLASS IIb

1. **Closure of an ASD, either percutaneously or surgically, may be considered in the presence of net left-to-right shunting, pulmonary artery pressure less than two thirds systemic levels, PVR less than two thirds systemic vascular resistance, or when responsive to either pulmonary vasodilator therapy or test occlusion of the defect (patients should be treated in conjunction with providers who have expertise in the management of pulmonary hypertensive syndromes). (*Level of Evidence: C*)**
2. **Concomitant Maze procedure may be considered for intermittent or chronic atrial tachyarrhythmias in adults with ASDs. (*Level of Evidence: C*)**

CLASS III

1. **Patients with severe irreversible PAH and no evidence of a left-to-right shunt should not undergo ASD closure. (*Level of Evidence: B*)**

Surgical closure has been the "gold standard" form of treatment, with excellent late outcome. A surgeon not trained in CHD should be cautious when planning to close a secundum ASD, because the intraoperative discovery of an unexpected primum ASD or partial anomalous pulmonary venous drainage can present challenges.

Primary operation includes pericardial patch closure or direct suture closure. Tricuspid valve repair should be performed for significant tricuspid regurgitation (TR). Anomalous pulmonary venous drainage should be repaired. The Warden procedure (translocation of the superior vena cava to the right atrial appendage) may be applied to the sinus venosus ASD when the anomalous pulmonary venous drainage enters the mid or upper superior vena cava. A concomitant Maze procedure may be performed for intermittent/chronic atrial fibrillation/flutter. The surgical approach can be by right thoracotomy or sternotomy, and more limited incisions are feasible with either approach.

Early mortality is approximately 1% in the absence of PAH or other major comorbidities. Long-term follow-up is excellent, and preoperative symptoms decrease or abate. The incidence of atrial fibrillation/flutter is reduced when concomitant antiarrhythmic procedures (eg, Maze) are performed; however, atrial arrhythmias may occur de novo after repair.

The need for reoperation of residual/recurrent ASD is uncommon. Superior vena cava stenosis or pulmonary vein stenosis may occur after closure of sinus venosus ASD.

2.5.3. Indications for Closure of Atrial Septal Defect

Small ASDs with a diameter of less than 5 mm and no evidence of RV volume overload do not impact the natural history of the individual and thus may not require closure unless associated with paradoxical embolism. Larger defects with evidence of RV volume overload on echocardiography usually only cause symptoms in the third decade of life, and closure is usually indicated to prevent long-term complications such as atrial arrhythmias, reduced exercise tolerance, hemodynamically significant TR, right-to-left shunting and embolism during pregnancy, overt congestive cardiac failure, or pulmonary vascular disease that may develop in up to 5% to 10% of affected (mainly female) individuals.

2.5.4. Catheter Intervention

The development of percutaneous transcatheter closure techniques has provided an alternative method of closure for uncomplicated secundum ASDs with appropriate morphology (260–262). Currently, the majority of secundum ASDs can be closed with a percutaneous catheter technique. When this is not feasible or is not appropriate, surgical closure is recommended.

Sinus venosus, coronary sinus, and primum defects are not amenable to device closure. An ASD with a large septal aneurysm or a multifenestrated atrial septum requires careful evaluation by and consultation with interventional cardiologists before device closure is selected as the method of repair.

2.5.5. Key Issues to Evaluate and Follow-Up

Key issues to evaluate and monitor in adults with ASD are listed in Table 10.

2.6. Recommendations for Postintervention Follow-Up

CLASS I

1. **Early postoperative symptoms of undue fever, fatigue, vomiting, chest pain, or abdominal pain may represent postpericardiotomy syndrome with tamponade and should prompt immediate evaluation with echocardiography. (*Level of Evidence: C*)**
2. **Annual clinical follow-up is recommended for patients postoperatively if their ASD was repaired as an adult and the following conditions persist or develop:**
   a. **PAH. (*Level of Evidence: C*)**
   b. **Atrial arrhythmias. (*Level of Evidence: C*)**
   c. **RV or LV dysfunction. (*Level of Evidence: C*)**
   d. **Coexisting valvular or other cardiac lesions. (*Level of Evidence: C*)**
3. **Evaluation for possible device migration, erosion, or other complications is recommended for patients 3 months to 1 year after device closure and periodically thereafter. (*Level of Evidence: C*)**
4. **Device erosion, which may present with chest pain or syncope, should warrant urgent evaluation. (*Level of Evidence: C*)**

Follow-up for patients after device closure requires clinical assessment of symptoms of arrhythmia, chest pain, or embolic events and echocardiographic surveillance for device position, residual shunting, and complications such as thrombus formation or pericardial effusion. The frequency of echocardiographic follow-up is usually at 24 hours, 1 month, 6 months, and 1 year and at regular intervals thereafter.

Pericardial effusions and cardiac tamponade may occur up to several weeks after surgical repair of ASDs and should be evaluated by clinical examination and echocardiography before hospital discharge and at the early postoperative visits. Patients and their primary care physicians should be instructed to report fever or unusual symptoms of chest or abdominal pain and vomiting or undue fatigue in the first weeks after surgery, because they might represent early signs of cardiac tamponade. Assessment of pulmonary pressure, RV function, and residual atrial shunting should also be made during follow-up echocardiography. Clinical and ECG surveillance for recurrent or new-onset arrhythmia is an important feature of postoperative evaluation. Periodic long-term clinical follow-up is required for patients postoperatively if their ASD was repaired as an adult, if PAH was present preoperatively, if there were atrial arrhythmias either preoperatively or postoperatively, if there was RV or LV dysfunction preoperatively or postoperatively, or if there are coexisting valvular or other cardiac lesions. Patients with ASD who have undergone surgical closure in childhood are generally free of late complications.

2.6.1. Endocarditis Prophylaxis

Endocarditis does not occur in patients with isolated ASDs and is usually associated with concomitant valvular lesions, such as a cleft mitral valve (94). Endocarditis prophylaxis is

Table 10. Key Issues to Evaluate and Monitor in Adults With Atrial Septal Defects

Before Intervention	After Intervention
Symptoms	After surgical intervention
• Dyspnea	• Pericardial effusion/constriction
• Fatigue	• Residual shunt
• Exercise intolerance	• RV systolic and diastolic dysfunction
• Palpitations	• Pulmonary artery pressure
• Syncope	• Mitral regurgitation
Shunt size	• Pulmonary vein stenosis or caval vein stenosis (sinus venosus defects)
• RV volume overload by echocardiography	• Arrhythmia
• Pulmonary plethora on chest x-ray	• Tricuspid regurgitation
Defect size, location, and septal rims	After catheter intervention
• Secundum	• Device misalignment
• Primum	• Device embolization
• Sinus venosus	• Device erosion of atrial wall or aorta
• Coronary sinus	• Device impingement on adjacent structures
Associated lesions	• AV valves
• Cleft MV	• Coronary sinus
• Valvular PS	• SVC
• Anomalous pulmonary veins	• Pulmonary veins
• Mitral valve prolapse	• Aorta
• Persistent L-SVC	• Device thrombosis
• Associated coronary artery disease	• Endocarditis for the first 6 months or with a residual defect
Pulmonary pressure	• Residual shunt
• Echocardiography estimate by TR jet	
• Systolic septal flattening	
Arrhythmia	
• Atrial fibrillation	
• Atrial flutter	
• Paroxysmal atrial tachycardia	
• Sick sinus syndrome	
• Heart block	
Paradoxical embolus; avoid	
• Venous stasis	
• Unfiltered IV lines	
• Indwelling catheters	

RV indicates right ventricular; MV, mitral valve; PS, pulmonic stenosis; L-SVC, left superior vena cava; TR, tricuspid regurgitation; IV, intravenous; AV, atrioventricular; and SVC, superior vena cava.

therefore not indicated for isolated ASDs before or after surgery except for the first 6 months after closure (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information).

2.6.2. Recommendation for Reproduction

CLASS III

1. Pregnancy in patients with ASD and severe PAH (Eisenmenger syndrome) is not recommended owing to excessive maternal and fetal mortality and should be strongly discouraged. (*Level of Evidence: A*)

Pregnancy in patients with ASDs is generally well tolerated, with no maternal mortality and no significant maternal or fetal morbidity. Although the left-to-right shunt may increase with the increase in cardiac output during pregnancy, this is counterbalanced by the decrease in peripheral resistance.

Women with large shunts and PAH may experience arrhythmias, ventricular dysfunction, and progression of PAH. Pregnancy in patients with ASD and severe PAH (Eisenmenger syndrome) is contraindicated owing to excessive maternal and fetal mortality and should be strongly discouraged (263,264). Paradoxical embolism may occasionally be encountered in small and large ASDs (134,265).

Familial occurrence of secundum ASDs is well recognized, and in some kindreds, a defect has been localized to chromosome 5 (266). Familial ASD with AV conduction defect is an autosomal dominant trait, with mutations in the cardiac homeobox transcription factor gene NKX2–5 (267,268).

Table 11. Ventricular Septal Defect Nomenclature

VSD Type	Synonyms	Characteristics
Type 1	• Conal • Subpulmonary • Infundibular • Supracristal • Doubly committed juxta-arterial	• Lies beneath the semilunar valve(s) in the conal or outlet septum
Type 2	• Perimembranous • Paramembranous • Conoventricular	• Confluent with the membranous septum • Bordered by an AV valve, not including type 3 VSDs • May extend into the inlet or outlet areas
Type 3	• Inlet • AV canal type	• Involves the inlet of the ventricular septum immediately inferior to the AV valve apparatus
Type 4	• Muscular	• Completely surrounded by muscle • May be midmuscular, apical, posterior, or anterior • May be multiple

Modified from Jacobs JP, Burke RP, Quintessenza JA, Mavroudis C. Congenital heart surgery nomenclature and database project: ventricular septal defect. *Ann Thorac Surg.* 2000;69:S25–35 (280). Copyright 2000, with permission from Elsevier.
AV indicates atrioventricular; and VSD, ventricular septal defect.

The risk of transmission of CHD to offspring of women with sporadic ASD is estimated at 8% to 10% (133,269). Genetic syndromes with skeletal abnormalities associated with ASD include a variety of heart-hand syndromes, of which Holt-Oram syndrome is best known (270–272). Both secundum and primum ASDs are associated with trisomy 21 (Down syndrome). Because of the possibility of familial occurrence, a careful family history should be taken in patients with ASD, and parents and offspring should be evaluated clinically for possible septal defect, conduction disturbances, and skeletal anomalies.

2.6.3. Activity

Patients with small ASDs and without PAH have normal exercise capacity and do not need any limitation of physical activity. In those patients with large left-to-right shunts, exercise is often self-limited owing to decreased cardiopulmonary function (273). Symptomatic supraventricular or ventricular arrhythmias may also compromise exercise capacity and impose limitations on engagement in competitive sports. Patients with significant PAH (peak systolic pulmonary artery pressure greater than 40 mm Hg) should limit their activity to low-intensity sports. Severe PAH with right-to-left shunting is usually self-limiting, but participation in athletics or active physical effort should be avoided (274).

3. Ventricular Septal Defect

3.1. Definition

VSD is the most common congenital heart defect at birth (275) and presents in approximately 3.0 to 3.5 infants per 1000 live births. Because there is a high incidence of spontaneous closure of small VSDs, the incidence is much less in older infants and particularly in adults (276,277).

There are 4 anatomic types of VSDs (278–280), with multiple synonyms for each type. In an effort to establish a unified reporting system, the Society for Thoracic Surgery's Congenital Heart Surgery Database Committee and representatives from the European Association for Cardiothoracic Surgery developed a classification scheme, as shown in Table 11.

Type 1 VSDs lie in the outflow portion of the RV and account for approximately 6% of defects in non-Asian populations but up to 33% in Asian patients (278). Spontaneous closure of this defect is uncommon.

Type 2 or perimembranous VSDs are the most common defects, and almost 80% of defects are in this location. This defect is in the membranous septum and is adjacent to the septal leaflet of the tricuspid valve, which can become adherent to the defect, thus forming a pouch or "aneurysm" of the ventricular septum. This pouch will limit left-to-right shunting and can result in partial or complete closure of the defect. On the LV side of the septum, the defect is adjacent to the aortic valve.

Type 3 or inlet VSDs occur in the lower part of the right ventricle and adjacent to the tricuspid valve (278–280). These defects typically occur in patients with Down syndrome.

Type 4 or muscular VSDs can be located centrally (midmuscular), apically, or at the margin of the septum and RV free wall. They can be multiple in number. Spontaneous closure is common, and although these defects can account for up to 20% of VSDs in infants, the incidence is much lower in adults (276–278).

3.1.1. Associated Lesions

Although VSD is most often an isolated lesion, it is a common component of complex abnormalities such as conotruncal defects (eg, tetralogy of Fallot, TGA). VSD can also be associated with left-sided obstructive lesions such as SubAS and coarctation of the aorta. A subpulmonary (supracristal) VSD is often associated with progressive aortic valve regurgitation caused by prolapse of the aortic cusp (usually right) through the defect.

Table 12. Key Issues to Be Monitored in Adults With Ventricular Septal Defects

Unrepaired or Repaired/Catheter Closure	Repaired/Catheter Closure
• Development of aortic regurgitation	• Degree of shunting if residual VSD
• Assessment of associated coronary artery disease	• Development of arrhythmia/heart block
• Development of tricuspid regurgitation	• Thromboembolic complications (rare)
• Assessment of degree of left-to-right shunt	
• Ventricular dysfunction	
• Assessment of pulmonary pressure	
• Development of subpulmonary stenosis, usually due to DCRV	
• Development of discrete subaortic stenosis	

DCRV indicates double-chambered right ventricle; and VSD, ventricular septal defect.

3.2. Clinical Course (Unrepaired)

It is unlikely for an adult with an isolated VSD to present with no prior workup/diagnosis. Possible scenarios include the following:

- An asymptomatic patient with a systolic murmur previously thought to be an innocent murmur
- Fever and bacteremia secondary to IE
- A new diastolic murmur of AR secondary to aortic valve prolapse
- Cyanosis and exercise intolerance secondary to the progressive development of pulmonary vascular disease.

Clinical presentation in an isolated VSD depends largely on defect size and PVR. Small defects that are less than or approximately equal to 25% the size of the aortic annulus diameter have small left-to-right shunts, no left ventricle volume overload, and no PAH and present as systolic murmurs.

VSDs that are more than 25% but less than 75% of the aortic diameter can be classified as moderate in size, with small to moderate left-to-right shunts, mild to moderate LV volume overload, and mild or no PAH. Patients may remain asymptomatic or develop symptoms of mild congestive heart failure. Symptoms usually abate with medical treatment and with time as the size of the VSD decreases in absolute terms or relative to increasing body size.

If the defect is large (greater than or equal to 75% of the aortic diameter), there is usually a moderate to large left-to-right shunt, LV volume overload, and PAH. Most adult patients with large VSDs will have a history of congestive heart failure in infancy. Rarely, patients with large VSDs do not develop large left-to-right shunts and do not have the normal postnatal fall in PVR. They can present with right-to-left shunting and Eisenmenger syndrome later in childhood or as adolescents or young adults. Key issues to follow in patients with VSD are summarized in Table 12. Patients with a small VSD who develop endocarditis may present with pulmonary embolism or cerebral abscess. Spontaneous closure of small defects can occur at any age but most commonly occurs in infancy (277,281,282). Postsurgical presentations include signs and symptoms associated with IE, AR, heart block, LV dysfunction, PAH, TR, recurrent VSD, and ventricular arrhythmias.

3.3. Clinical Features and Evaluation of the Unoperated Patient

3.3.1. Clinical Examination

VSD is characterized clinically by a systolic murmur that is usually maximal at the left lower sternal border. When RV pressure is low, the VSD murmur is blowing and pansystolic. With incremental increases in RV pressure, the murmur is shorter, softer, and lower pitched. Small, muscular VSDs are usually very high-pitched and occupy early systole only because muscular contraction closes the defect.

3.3.2. Electrocardiogram

In patients with large VSD and significant PAH, the ECG will show biventricular hypertrophy or isolated RV hypertrophy, depending on the extent to which the LVOT has diminished in response to the reduction in left-to-right shunt.

3.3.3. Chest X-Ray

Patients with a small VSD will have a normal chest x-ray. The presence of a significant left-to-right shunt will create the appearance of left atrial and LV enlargement and increased pulmonary vascular markings. Patients with significant PAH will not demonstrate LV enlargement but will have a prominent pulmonary artery segment and diminished pulmonary vascular markings at the periphery of the lung.

3.3.4. Echocardiography

Echocardiography-Doppler is the mainstay of modern diagnosis. Transthoracic echocardiographic studies are almost always diagnostic in children and adolescents and in most adults with good echocardiographic windows. Data to be obtained include the number of defects, location of defect(s), chamber sizes, ventricular function, presence or absence of aortic valve prolapse and/or regurgitation, presence or absence of RV or LV outflow obstruction, and presence or absence of TR. Estimation of RV systolic pressure from TR jet, VSD jet, and/or septal configuration should be a part of the study. In adults with poor echocardiographic windows, TEE may be necessary.

Echocardiography-Doppler of postoperative patients should focus on the presence or absence and location of residual shunting and the evaluation of pulmonary artery pressure by TR or pulmonary regurgitation jet velocity. In addition, patients should be evaluated for AR, ventricular function, and RV or LV outflow obstruction.

3.3.5. Magnetic Resonance Imaging/Computed Tomography

MRI or CT may be useful, if local expertise in cardiac studies is available, for the following:

- Assessment of pulmonary artery, pulmonary venous, and aortic anatomy if there are coexisting lesions
- To confirm the anatomy of unusual VSDs such as inlet or apical defects not well seen by echocardiography.

3.3.6. Recommendations for Cardiac Catheterization

CLASS I

1. **Cardiac catheterization to assess the operability of adults with VSD and PAH should be performed in an ACHD regional center in collaboration with experts. (*Level of Evidence: C*)**

CLASS IIa

1. **Cardiac catheterization can be useful for adults with VSD in whom noninvasive data are inconclusive and further information is needed for management. Data to be obtained include the following:**
   a. **Quantification of shunting. (*Level of Evidence: B*)**
   b. **Assessment of pulmonary pressure and resistance in patients with suspected PAH. Reversibility of PAH should be tested with various vasodilators. (*Level of Evidence: B*)**
   c. **Evaluation of other lesions such as AR and double-chambered right ventricle. (*Level of Evidence: C*)**
   d. **Determination of whether multiple VSDs are present before surgery. (*Level of Evidence: C*)**
   e. **Performance of coronary arteriography is indicated in patients at risk for coronary artery disease. (*Level of Evidence: C*)**
   f. **VSD anatomy, especially if device closure is contemplated. (*Level of Evidence: C*)**

3.4. Diagnostic Problems and Pitfalls

Problems and pitfalls in the diagnosis of adults with VSDs include the following:

- Patients with loud murmur of a known small VSD may develop double-chambered right ventricle or SubAS with little appreciable change in murmur.
- Patients with a small VSD and aortic valve prolapse may develop progressive AR.
- Patients with unrecognized RV outflow obstruction associated with a VSD may have a high-velocity TR jet and may be assumed to have PAH.
- A VSD jet may be mistaken for a TR jet in a patient with normal pulmonary pressure assumed to have PAH.

3.5. Management Strategies

3.5.1. Recommendation for Medical Therapy

CLASS IIB

1. **Pulmonary vasodilator therapy may be considered for adults with VSDs with progressive/severe pulmonary vascular disease (refer to Section 9, Pulmonary Hypertension/Eisenmenger Physiology). (*Level of Evidence: B*)**

3.5.2. Recommendations for Surgical Ventricular Septal Defect Closure

CLASS I

1. **Surgeons with training and expertise in CHD should perform VSD closure operations. (*Level of Evidence: C*)**
2. **Closure of a VSD is indicated when there is a Qp/Qs (pulmonary–to–systemic blood flow ratio) of 2.0 or more and clinical evidence of LV volume overload. (*Level of Evidence: B*)**
3. **Closure of a VSD is indicated when the patient has a history of IE. (*Level of Evidence: C*)**

CLASS IIa

1. **Closure of a VSD is reasonable when net left-to-right shunting is present at a Qp/Qs greater than 1.5 with pulmonary artery pressure less than two thirds of systemic pressure and PVR less than two thirds of systemic vascular resistance. (*Level of Evidence: B*)**
2. **Closure of a VSD is reasonable when net left-to-right shunting is present at a Qp/Qs greater than 1.5 in the presence of LV systolic or diastolic failure. (*Level of Evidence: B*)**

CLASS III

1. **VSD closure is not recommended in patients with severe irreversible PAH. (*Level of Evidence: B*)**

Primary operation for isolated VSD includes patch closure, usually with a synthetic material (eg, Dacron, polytetrafluoroethylene [Gore-Tex]), and, rarely, primary closure. Careful intraoperative inspection of the muscular septum by TEE is indicated to rule out associated VSDs that might manifest by shunting only after closure of the dominant VSD. Associated RV outflow obstruction should be treated with resection or RV outflow patch enlargement, AR by aortic valve replacement (AVR), and SubAS usually by resection of a subaortic membrane and rarely by a Konno procedure tricuspid valve repair if there is associated significant TR.

Early mortality is approximately 1% in the absence of elevated PVR. Late survival is excellent when ventricular function is normal. PAH may regress, progress, or remain unchanged. Atrial fibrillation may occur and is more likely if there has been chronic volume overload resulting in left atrial dilatation. Complete heart block may occur early or late after surgical repair. Ventricular arrhythmias are uncommon unless repair is performed late in life. The need for reoperation for a residual VSD is uncommon. Late reoperation is occasionally required for TR or AR.

3.5.3. Recommendation for Interventional Catheterization

CLASS IIb

1. **Device closure of a muscular VSD may be considered, especially if the VSD is remote from the tricuspid valve and the aorta, if the VSD is associated with severe left-sided heart chamber enlargement, or if there is PAH. (*Level of Evidence: C*)**

Indications for catheter device closure of VSD include residual defects after prior attempts at surgical closure, restrictive VSDs with a significant left-to-right shunt, trauma, or iatrogenic artifacts after surgical replacement of the aortic valve. Indications for closure of restrictive VSDs in the adult population include a history of bacterial endocarditis or a hemodynamically significant left-to-right shunt (Qp/Qs greater than 1.5:1).

Percutaneous closure of VSD offers an attractive alternative to surgical management in patients with increased surgi-

cal risk factors, multiple previous cardiac surgical interventions, poorly accessible muscular VSDs, or "Swiss cheese"–type VSDs. At the time of this writing, US Food and Drug Administration approval for device closure of VSDs in the United States is limited to closure of muscular VSDs. Experience with percutaneous closure of other types of VSDs has been obtained at centers outside the United States or in centers with investigational protocols.

Complications have been reported in as many as 10.7% of patients and most frequently include rhythm and conduction abnormalities, as well as hypotensive episodes or blood loss (283); however, complications are significantly associated with a lower patient weight (below 10 kg), and therefore the adult population is likely to represent a lower-risk group for percutaneous closure of muscular VSDs. Complications after closure of perimembranous VSDs predominantly include rhythm and conduction abnormalities, as well as the potential for new or increased AR or TR, which is usually of a trivial or mild degree.

Success rates of the procedure are high, with closure rates with the membranous device of up to 92% at 15 minutes after device implantation and a 92% rate of complete closure at the 12-month follow-up for device closure of muscular VSD. These results, unfortunately, are not matched in patients undergoing closure of a postinfarct VSD because of the often moribund status of these patients and the tendency of the VSD to enlarge over time owing to ongoing necrosis.

3.6. Key Issues to Evaluate and Follow-Up

3.6.1. Recommendations for Surgical and Catheter Intervention Follow-Up

CLASS I

1. **Adults with VSD with residual heart failure, shunts, PAH, AR, or RVOT or LVOT obstruction should be seen at least annually at an ACHD regional center. (*Level of Evidence: C*)**
2. **Adults with a small residual VSD and no other lesions should be seen every 3 to 5 years at an ACHD regional center. (*Level of Evidence: C*)**
3. **Adults with device closure of a VSD should be followed up every 1 to 2 years at an ACHD center depending on the location of the VSD and other factors. (*Level of Evidence: C*)**

Adults with no residual VSD, no associated lesions, and normal pulmonary artery pressure do not require continued follow-up at a regional ACHD center except on referral from their cardiologist or physician. Patients who develop bifascicular block or transient trifascicular block after VSD closure are at risk in later years for the development of complete heart block and should be followed up yearly by history and ECG and have periodic ambulatory monitoring and/or exercise testing.

3.6.2. Recommendation for Reproduction

CLASS III

1. **Pregnancy in patients with VSD and severe PAH (Eisenmenger syndrome) is not recommended owing to excessive maternal and fetal mortality and should be strongly discouraged. (*Level of Evidence: A*)**

Women with small VSDs, no PAH, and no associated lesions have no increased cardiovascular risk for pregnancy. Women with PAH should be counseled against pregnancy (refer to Section 9, Pulmonary Hypertension/Eisenmenger Physiology).

Pregnancy is generally well tolerated, with no maternal mortality and no significant maternal or fetal morbidity. Although the left-to-right shunt may increase with the increase in cardiac output during pregnancy, this is counterbalanced by the decrease in peripheral resistance. Women with large shunts and PAH may experience arrhythmias, ventricular dysfunction, and progression of PAH.

3.6.3. Activity

No activity restrictions are indicated for patients with small VSDs, no associated lesions, and normal ventricular function. If pulmonary vascular disease is present, activity is usually self-restricted, but patients should be advised against strenuous exercise or travel to altitudes above 5000 feet. Long-distance air travel should be approached with caution to avoid dehydration, with specific recommendation by an ACHD specialist concerning the need for supplemental oxygen (refer to Section 9, Pulmonary Hypertension/Eisenmenger Physiology).

4. Atrioventricular Septal Defect

4.1. Definition

The terms AVSD, AV canal defect, and endocardial cushion defect can be used interchangeably to describe this group of defects. The basic morphology of AVSD includes a large, central defect that may lie above the AV valve (refer to Section 2, Atrial Septal Defect) or may extend to variable degrees above and below the AV valve; therefore, the interventricular communication can range from large to small. There is a common AV valve annulus that stretches across both ventricles. There may be a common superior leaflet, or the superior leaflet may be separated at its distal margin into right and left components. The AV valve may be misaligned with respect to the ventricles, in association with hypoplasia of the right or left ventricle. The left AV valve is a trileaflet valve made of superior and inferior bridging leaflets separated by a mural leaflet. There may be abnormal lateral rotation of the posteromedial papillary muscle. Most complete AVSDs are in Down syndrome patients (more than 75%). Most partial AVSDs occur in non–Down syndrome patients (more than 90%).

4.2. Associated Lesions

Tetralogy of Fallot and other conotruncal anomalies and heterotaxy syndromes also occur in association with AVSD.

4.3. Clinical Features and Evaluation

Most patients will have had surgery in childhood. The unrepaired adult may be asymptomatic or may present with congestive heart failure, exertional limitation, PAH and cyanosis, IE, or atrial flutter/fibrillation. Patients with partial AVSD are likely to become symptomatic at a younger age if significant left AV valve regurgitation is present.

4.3.1. Clinical Examination

Physical examination of the unoperated patient may show findings of an ASD, a VSD, AV valve regurgitation, LVOT obstruction, or PAH with cyanosis. A patient with severe PAH may have no murmur, a single loud second heart sound, and cyanosis/clubbing.

The typical repaired patient will have a normal examination apart from an apical systolic murmur if there is residual mitral regurgitation or subaortic obstruction. Subaortic obstruction may occur naturally in association with abnormal AV valve attachments or may be the consequence of surgery. In addition, the surgical repair may have created AV valve stenosis. Cyanosis should not be present in the absence of Eisenmenger syndrome or RV outflow obstruction.

4.3.2. Electrocardiogram

The typical ECG shows superior left-axis deviation with a counterclockwise loop in the frontal plane. First-degree AV block may be present. Atrial flutter or fibrillation may develop in the older patient. Left atrial enlargement and LV hypertrophy may be present if there is significant left AV valve regurgitation. RV hypertrophy may predominate if there is PAH or associated RVOT obstruction.

4.3.3. Chest X-Ray

Cardiomegaly may be present due to dilation of the right or left AV heart chambers, depending on the degree and direction of AV valve regurgitation and the degree and level of left-to-right shunting. Increased pulmonary vascular markings are present when there is a significant left-to-right shunt. Pulmonary venous congestion may be seen when there is long-standing mitral regurgitation. In patients with PAH, a prominent main pulmonary artery segment and pruning of distal pulmonary vessels may be present.

4.3.4. Echocardiography

In the patient with a partial and unrepaired AVSD, TTE is the primary imaging modality and should include demonstration of the borders of the primum ASD, a VSD (if present), the morphology and function of the AV valve, ventricular size and shunting, and SubAS (if present). In the patient with a complete and unrepaired AVSD, this will include the presence and size of the septal defect, the morphology and function of the common AV valve, and ventricular size and function. When the ventricular portion of the septal defect is large, the ventricular septum may be deficient apically and inferiorly. Pulmonary artery pressures (expected to be very high in complete AVSD) should be evaluated by measuring TR and pulmonary regurgitation jet velocity with simultaneous systemic blood pressure measurement. Evidence of subaortic obstruction, caused by AV valve attachments to the crest of the interventricular septum, should be sought by imaging and Doppler. In the postrepair patient, residua may include left AV valve dysfunction, SubAS, VSD patch leak, and PAH. It may be difficult to distinguish residual LV to right atrial shunt from TR with RV hypertension. The failure to distinguish these may result in erroneous diagnosis of PAH.

4.3.5. Magnetic Resonance Imaging

MRI may be useful to evaluate venous and arterial anatomy when associated lesions are suspected. Three-dimensional MRI is sometimes helpful in delineating leaflet morphology and outflow anatomy.

4.3.6. Recommendation for Heart Catheterization

CLASS IIa

1. **Cardiac catheterization is reasonable to assess PAH and test vasoreactivity in patients with repaired or unrepaired AVSD. (*Level of Evidence: B*)**

Heart catheterization has a limited role in the assessment of these patients unless noninvasive findings are equivocal. Evaluation of PAH and coronary anatomy may be needed when reoperation is being considered. Hemodynamic data may also be needed when noninvasive studies have not been able to provide this information.

4.3.7. Exercise Testing

Exercise testing may be used to objectively assess functional capacity.

4.4. Management Strategies

4.4.1. Medical Therapy

Most patients need no regular medication in the absence of specific problems. ACE inhibitors and/or diuretics may be used in patients with AV valve regurgitation and symptoms of chronic heart failure. Pulmonary vasodilation therapy may be indicated in patients with PAH and no significant left-to-right shunt who are deemed to be at high risk for surgical repair, but this should be approached with caution because of the potential for producing a significant right-to-left shunt.

4.4.2. Recommendations for Surgical Therapy

CLASS I

1. **Surgeons with training and expertise in CHD should perform operations for AVSD. (*Level of Evidence: C*)**
2. **Surgical reoperation is recommended in adults with previously repaired AVSD with the following indications:**
   a. **Left AV valve repair or replacement for regurgitation or stenosis that causes symptoms, atrial or ventricular arrhythmias, a progressive increase in LV dimensions, or deterioration of LV function. (*Level of Evidence: B*)**
   b. **LVOT obstruction with a mean gradient greater than 50 mm Hg or peak instantaneous gradient greater than 70 mm Hg, or a gradient less than 50 mm Hg in association with significant mitral regurgitation or AR. (*Level of Evidence: B*)**
   c. **Residual/recurrent ASD or VSD with significant left-to-right shunting (refer to Section 2, Atrial Septal Defect, and Section 3, Ventricular Septal Defect). (*Level of Evidence: B*)**

Primary operation is rarely recommended for complete AVSD in adults because of pulmonary vascular obstructive disease. Unoperated partial or transitional AVSD, also known as partial or transitional AV canal, may not be identified until

adulthood. Primary repair is generally recommended provided there is no fixed PAH.

Complete AVSD is usually repaired during infancy because of the risk of accelerated pulmonary vascular disease. Partial AVSD, also known as partial AV canal, is usually repaired in early childhood. The timing of repair of intermediate or transitional AVSD depends on the size of the VSD and the degree of shunting. Complete repair usually includes patch closure of the septal defect. Suture of the cleft in the left AV valve is dependent on leaflet morphology and surgical choice. Pulmonary artery banding of complete AVSD is rarely performed and is reserved for complex lesions.

Rerepair includes valve repair or replacement for left AV regurgitation or stenosis. LVOT obstruction is treated most commonly by resection of the fibrous stenosis/membrane, modified Konno procedure, or Konno-Rastan procedure. Suture or patch closure is performed for residual/recurrent ASD or VSD. A concomitant Maze procedure may be performed for intermittent or chronic atrial fibrillation/flutter. Management of patients should be in tertiary CHD centers or children's hospitals with experienced medical and surgical personnel.

4.5. Key Issues to Evaluate and Follow-Up

4.5.1. Key Postoperative Issues

Late complications may include left AV valve regurgitation and/or stenosis, LVOT obstruction with or without AR, and the development of heart block. Left AV valve regurgitation or stenosis requiring reoperation may occur in approximately 5% to 10% of patients. LVOT obstruction may occur in 5% of patients.

In the patient with prior repair, the onset of atrial arrhythmias should prompt a search for an underlying hemodynamic abnormality. Subaortic obstruction should be ruled out when there is a loud or harsh systolic murmur. Progressive left AV valve regurgitation may occur. The presence of an apical diastolic rumble without evidence of left-sided heart volume overload should prompt evaluation for left AV valve stenosis, particularly when there is evidence of PAH.

4.5.2. Evaluation and Follow-Up of the Repaired Patient

All patients should be assessed by and have periodic or regular follow-up with a cardiologist who has expertise in ACHD. The frequency, although typically annual, may be determined by the extent and degree of residual abnormalities. Appropriate imaging (2-dimensional and Doppler echocardiography in most patients) should be undertaken by staff trained in imaging of complex congenital heart defects and should include serial observation of AV valve function and evaluation of the LVOT. Periodic 24-hour ambulatory monitoring should be performed to assess rhythm abnormalities. Periodic cardiopulmonary testing may be helpful. Other testing should be arranged in response to clinical problems.

4.5.3. Electrophysiology Testing/Pacing Issues in Atrioventricular Septal Defects

In AVSD, the AV node and bundle of His are displaced inferiorly along the AV ring (182). This position puts the conduction system at risk for injury during surgical repair (169). Functional properties of these displaced conduction tissues can be suboptimal early in life (including the possibility of congenital complete heart block) and may worsen with age. For these reasons, the status of AV conduction must be monitored regularly with ECG and periodic Holter monitoring in adults with repaired or palliated AVSD.

4.5.4. Recommendations for Endocarditis Prophylaxis

CLASS IIa

1. **Antibiotic prophylaxis before dental procedures that involve manipulation of gingival tissue or the periapical region of teeth or perforation of the oral mucosa is reasonable in patients with CHD with the highest risk for adverse outcome from IE, including those with the following indications:**
   a. **Prosthetic cardiac valve or prosthetic material used for cardiac valve repair. (*Level of Evidence: B*)**
   b. **Previous IE. (*Level of Evidence: B*)**
   c. **Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: B*)**
   d. **Completely repaired CHD with prosthetic materials, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure. (*Level of Evidence: B*)**
   e. **Repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device that inhibit endothelialization. (*Level of Evidence: B*)**
2. **It is reasonable to consider antibiotic prophylaxis against IE before vaginal delivery at the time of membrane rupture in select patients with the highest risk of adverse outcomes. This includes patients with the following indications:**
   a. **Prosthetic cardiac valve or prosthetic material used for cardiac valve repair. (*Level of Evidence: C*)**
   b. **Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: C*)**

CLASS III

1. **Prophylaxis against IE is not recommended for nondental procedures (such as esophagogastroduodenoscopy or colonoscopy) in the absence of active infection. (*Level of Evidence: C*)**

4.6. Reproduction

4.6.1. Genetic Aspects

Trisomy 21, or Down syndrome, is commonly seen in association with AVSD. Such patients have a 50% risk of transmitting trisomy 21 and other genetic defects to their offspring. Reproductive counseling and discussion with the patient and those with medical power of attorney is warranted.

4.6.2. Recommendations for Pregnancy

CLASS I

1. **All women with a history of AVSD should be evaluated before conception to ensure that there are no significant residual hemodynamic lesions that might complicate the management of pregnancy. (*Level of Evidence: C*)**

2. The issue of pregnancy risk and preventive measures should be discussed with women with Down syndrome and their caregivers. (*Level of Evidence: C*)

Pregnancy is usually well tolerated by women who have had repair and who have no major residua, as well as by women with a primum defect who are functionally well. Pregnancy is not advised for women with severe PAH.

4.7. Exercise

Most patients with uncomplicated, repaired AVSD can enjoy unlimited activity. Most will have subnormal exercise performance when measured objectively, but this typically does not impact on a normal lifestyle. Patients with important clinical problems (eg, severe left AV valve regurgitation, ongoing arrhythmias, or important LVOT obstruction) will often be advised to limit their activity. Advice regarding elite athletic activity should be individualized.

5. Patent Ductus Arteriosus

5.1. Definition and Associated Lesions

PDA is a persistent communication between the aorta and the pulmonary artery. It can be isolated or may be present in association with all forms of CHD. The most common associated lesions are VSDs or ASDs.

5.2. Presentation and Clinical Course

Unoperated patients may present with a heart murmur or symptoms caused by a large left-to-right shunt, including shortness of breath and easy fatigability. If the PDA is large and nonrestrictive, the patient may present with Eisenmenger physiology, including differential cyanosis and clubbing. Patients are at an increased risk of developing endarteritis, heart failure, and pulmonary vascular disease.

5.3. Recommendations for Evaluation of the Unoperated Patient

CLASS I

1. Definitive diagnosis of PDA should be based on visualization by imaging techniques and demonstrations of the shunting across the defect (with or without evidence of clinically significant LV volume overload). (*Level of Evidence: C*)

CLASS III

1. Diagnostic cardiac catheterization is not indicated for uncomplicated PDA with adequate noninvasive imaging. (*Level of Evidence: B*)
2. Maximal exercise testing is not recommended in PDA with significant PAH. (*Level of Evidence: B*)

The diagnostic workup for a patient with a suspected PDA is directed at defining the presence and size of the PDA, the functional effect of the shunt on the left atrium and left ventricle, the pulmonary circulation, and any associated lesions.

5.3.1. Clinical Examination

If the PDA is moderate or large, the presence of a continuous machinery-type murmur, heard best at the left infraclavicular area, and increased pulses are almost diagnostic. If PAH is present, only a systolic murmur may be heard. A wide pulse pressure is present when the PDA is large and there is a large left-to-right shunt. This must be distinguished from other causes of wide pulse pressure, such as aortic insufficiency and hyperthyroidism. In a patient with a large ductus and PAH, the oxygen saturation in the upper and lower extremities may be helpful in diagnosis of a large PDA with right-to-left shunt at the ductal level, because unoxygenated blood from the ductus enters the aorta distal to the left subclavian artery, causing cyanosis and often clubbing in the lower extremities.

5.3.2. Electrocardiogram

The ECG may be normal if the ductus is small or may show left atrial enlargement and LV hypertrophy if there is a moderate left-to-right shunt. RV hypertrophy may be present if there is PAH.

5.3.3. Echocardiography

Echocardiography with color Doppler in the parasternal short-axis view is diagnostic of a PDA. Measurement of the transpulmonary gradient across the ductus with continuous-wave Doppler can estimate the pulmonary artery pressure; however, in cases of significant elevation of PVR, echocardiography may not be diagnostic, and cardiac catheterization and angiography may be indicated.

5.3.4. Chest X-Ray

The chest x-ray may or may not show cardiomegaly and increased pulmonary vascular markings, depending on the size of the left-to-right shunt. There may be a prominent proximal pulmonary artery segment indicating elevated pulmonary artery pressure. An enlarged left atrium and left ventricle due to the left-to-right shunt may point to the presence of a significant PDA. One should look for calcification in the region of the ductus, because a calcified ductus is at an increased risk of rupture during surgical repair (284–286).

5.3.5. Cardiac Catheterization

During cardiac catheterization, it is important to evaluate the degree of shunt (in either direction), the PVR, and the reactivity of the vascular bed. Angiography can determine the size and shape of the ductus. If size and shape are suitable, the PDA can be treated in the catheterization laboratory.

5.3.6. Magnetic Resonance Imaging/ Computed Tomography

Other diagnostic tests including CT scan or MRI of the chest usually are not necessary to diagnose a PDA.

5.4. Problems and Pitfalls

The differential diagnosis of a PDA on physical examination includes an aortopulmonary collateral, coronary arteriovenous fistula (CAVF), ruptured sinus of Valsalva, and a

VSD with associated AR. It is important to differentiate between PDA and coronary AV fistulas, which may have similar findings. Echocardiography and/or angiography should be able to differentiate all of these conditions. In older adults, the calcified ductus poses a surgical risk, and catheter intervention should be the first option.

5.5. Management Strategies

The anatomy of the PDA in the adult is remarkable for the presence of calcification and general tissue friability in the area of the aortic isthmus and pulmonary artery, which makes surgical manipulation in the adult more hazardous than in the child. The need for surgical closure of a PDA in the adult is uncommon. When a PDA occurs in isolation, device closure is usually feasible. A PDA in combination with other intracardiac pathology may be closed at the time of cardiac operation. However, when cardiac operation is required for other reasons (eg, coronary artery bypass grafting), preoperative device closure of the PDA should be considered given the potential anatomic difficulties often encountered with the PDA in the adult population.

The primary surgical approach may be via thoracotomy or sternotomy, with or without cardiopulmonary bypass. The presence of ductal calcification in the adult can increase surgical risk. Ligation and division or patch closure from inside the main pulmonary artery or inside the aorta can be performed, depending on the presence or absence of ductal calcification. The majority of PDAs (greater than 95%) can be closed by operation, and early mortality is low. Recanalization is rare. Complications may include recurrent laryngeal nerve or phrenic nerve injury or thoracic duct injury.

5.5.1. Recommendations for Medical Therapy

CLASS I

1. **Routine follow-up is recommended for patients with a small PDA without evidence of left-sided heart volume overload. Follow-up is recommended every 3 to 5 years for patients with a small PDA without evidence of left-heart volume overload. (*Level of Evidence: C*)**

CLASS III

1. **Endocarditis prophylaxis is not recommended for those with a repaired PDA without residual shunt. (*Level of Evidence: C*)**

5.5.2. Recommendations for Closure of Patent Ductus Arteriosus

CLASS I

1. **Closure of a PDA either percutaneously or surgically is indicated for the following:**
   a. **Left atrial and/or LV enlargement or if PAH is present, or in the presence of net left-to-right shunting. (*Level of Evidence: C*)**
   b. **Prior endarteritis. (*Level of Evidence: C*)**
2. **Consultation with ACHD interventional cardiologists is recommended before surgical closure is selected as the method of repair for patients with a calcified PDA. (*Level of Evidence: C*)**
3. **Surgical repair by a surgeon experienced in CHD surgery is recommended when:**
   a. **The PDA is too large for device closure. (*Level of Evidence: C*)**
   b. **Distorted ductal anatomy precludes device closure (eg, aneurysm or endarteritis). (82) (*Level of Evidence: B*)**

CLASS IIa

1. **It is reasonable to close an asymptomatic small PDA by catheter device. (*Level of Evidence: C*)**
2. **PDA closure is reasonable for patients with PAH with a net left-to-right shunt. (*Level of Evidence: C*)**

CLASS III

1. **PDA closure is not indicated for patients with PAH and net right-to-left shunt. (*Level of Evidence: C*)**

5.5.3. Surgical/Interventional Therapy

Currently, the 2 approaches for PDA closure are surgical closure (285,286) and percutaneous catheter closure. (287–316) Surgical closure of PDA in the adult may pose some problems due to the friability and/or calcification of the ductus, atherosclerosis, and aneurysm formation, as well as the presence of other unrelated comorbid conditions, such as coronary atherosclerosis or renal disease, that may adversely affect the perioperative risk. Adults with PDA are better suited for percutaneous closure with either the occlusion device or coils because of its high success and few complications (317). If the PDA is associated with other conditions that require surgical correction, the ductus may be closed during the same operation, although percutaneous closure of the PDA before other cardiac surgery may decrease the risk of cardiopulmonary bypass.

5.6. Key Issues to Evaluate and Follow-Up

Adults with large PDAs are likely to have Eisenmenger physiology. Such patients require frequent follow-up to monitor their progress/deterioration. Problems associated with Eisenmenger physiology are discussed in Section 9, Pulmonary Hypertension/Eisenmenger Physiology.

Patients who have undergone surgical/PDA closure can be discharged safely from follow-up once complete closure of the ductus is documented by TTE. Antibiotic prophylaxis is discontinued 6 months after PDA closure. Follow-up approximately every 5 years for patients who received a device is recommended because of the lack of long-term data on device closure with the occlusion device.

6. Left-Sided Heart Obstructive Lesions: Aortic Valve Disease, Subvalvular and Supravalvular Aortic Stenosis, Associated Disorders of the Ascending Aorta, and Coarctation

LVOT obstruction syndromes include SubAS, valvular AS, SupraAS, and aortic coarctation (318). Obstruction can occur singly or at multiple levels, as an isolated lesion or in combination with septal defects or conotruncal anomalies.

6.1. Definition

BAV is one of the most common congenital cardiovascular malformations, with an estimated incidence of 1% to 2% of the population. The prevalence of AS is harder to calculate because, unlike many other congenital heart lesions, a BAV

may develop significant obstruction or regurgitation after midlife, with a peak age range for surgical intervention between 60 and 80 years (275,319). There is male preponderance for AS. A BAV may be inherited, and family clusters have been studied (319,320).

BAV abnormalities arise from abnormal cusp formation during valvulogenesis, commonly with fusion between 2 cusps, forming 1 smaller and 1 larger cusp. Variants range from a nearly trileaflet aortic valve with cusp inequality to a unicuspid and dysplastic valve. A BAV can be predominately obstructive or regurgitant, depending on the degree of commissural fusion. The valve may dome in systole, but a dysplastic valve is poorly mobile and does not dome. In many patients with BAV, the histology of the aortic wall is similar to Marfan syndrome, with abnormalities of smooth muscle, extracellular matrix, elastin, and collagen (321–323).

In general, the severity of valvular AS in adults is graded mild, moderate, or severe on the basis of the valve area and jet velocity across the aortic valve as measured by Doppler echocardiography. Degrees of AS are defined in the 2006 ACC/AHA valvular heart disease guidelines as mild (a valve area greater than 1.5 cm^2, mean gradient less than 25 mm Hg, or jet velocity less than 3.0 ms), moderate (valve area 1.0 to 1.5 cm^2, mean gradient 25 to 40 mm Hg, or jet velocity 3.0 to 4.0 ms), or severe (valve area less than 1.0 cm^2, mean gradient greater than 40 mm Hg, or jet velocity greater than 4.0 m per s). Not all experts agree with these specifics, but these values provide a frame of reference in discussing severity of AS. In adolescents and young adults less than 30 years of age, AS severity is often reported on the basis of the mean gradient measured by Doppler echocardiography (112).

6.2. Associated Lesions

Abnormalities associated with BAV disease include SubAS, parachute mitral valve, VSD, PDA, or coarctation of the aorta with varying degrees of arch hypoplasia. A left-dominant coronary artery system is more frequent with BAV (324). Turner syndrome may be associated with AS in addition to aortic coarctation. The presence of multiple levels of left-sided heart obstructions (eg, SubAS, BAV, AS, coarctation, parachute mitral valve, or supramitral ring) is termed Shones syndrome. Patients presenting in childhood with LVOT obstruction generally have more complex or severe disease than those found to have BAV in adult life. BAV disease can be associated with progressive dilation of the aortic root, aortic aneurysm, and even rupture or dissection; intrinsic abnormalities of aortic wall elastin may result in ascending aortic dilation even with a normally functioning aortic valve.

6.3. Clinical Course (Unrepaired)

In adults, in the absence of superimposed acute endocarditis, BAV disease is usually a slowly progressive disorder with gradual development and progression of AS or AR (325,326). Asymmetrical flow patterns with turbulence subject the BAV to abnormally high stresses, which leads to thickening, calcification, and progressive stenosis or leaflet retraction and AR (42).

Evidence of echocardiographic "sclerosis" may be seen as early as the second decade, and calcification is often evident by the fourth decade (327). Most patients older than 45 years have significant BAV calcification and/or thickening, which often relates to hemodynamic severity. The presence of risk factors, such as hyperlipidemia, appears to be associated with progression of BAV stenosis (328,329).

Progressive AS is the most common complication of BAV, and many patients will require valve surgery or percutaneous valvuloplasty, with only one third or fewer remaining functionally normal by the fifth decade of life (330). The rate of progression of valvular AS is faster in those valves with anteroposterior-oriented line of closure and in those with greater closure-line eccentricity (327). In such patients, the BAV systolic peak pressure gradient increased 27 mm Hg per decade. Concomitant AR can also accelerate progression of valvular AS (327).

In addition to ascending aorta aneurysms and dissections, there can be familial aortocervicocephalic arterial dissections in conjunction with BAV disease (331). In a longitudinal study of the long-term outcomes of 622 adults with asymptomatic but hemodynamically severe AS at study inception, most developed symptoms within 5 years, and sudden death occurred at a rate of 1% per year (332).

Gradual progression of AR may occur in BAV due to several mechanisms (ie, leaflet prolapse or fibrosis and leaflet edge retraction or aortic root dilatation). Abrupt AR occurs owing to IE with leaflet destruction or perforation or, rarely, owing to loss of suspension of a leaflet due to intimal aortic dissection. Rarely, a flail aortic valve occurs spontaneously as a result of rupture of tenuous support at a raphe. Aortic dissection is well described in BAV, particularly if associated with aortic coarctation (333–335). The risk of aortic dissection in BAV is estimated at 5 to 9 times that of the general population (334,336).

6.4. Recommendations for Evaluation of the Unoperated Patient

Recommendations and guidelines concerning AS, BAV, and AR in the adult patient are also discussed in the 2006 valvular heart disease guidelines (112).

CLASS I

1. **Primary imaging and hemodynamic assessment of AS and aortic valve disease are recommended by echocardiography-Doppler to evaluate the presence and severity of AS or AR; LV size, function, and mass; and dimensions and anatomy of the ascending aorta and associated lesions. (*Level of Evidence: B*)**
2. **Echocardiography is recommended for reevaluation of patients with AS who experience a change in signs or symptoms and for assessment of changes in AS hemodynamics during pregnancy. (*Level of Evidence: B*)**
3. **In asymptomatic adolescents and young adults, echocardiography-Doppler is recommended yearly for AS with a mean Doppler gradient greater than 30 mm Hg or peak instantaneous gradient greater than 50 mm Hg and every 2 years for patients with lesser gradients. (*Level of Evidence: C*)**
4. **Cardiac catheterization is recommended when noninvasive measurements are inconclusive or discordant with clinical signs. (*Level of Evidence: C*)**

5. **Coronary angiography is recommended before aortic valve surgery for coronary angiography in adults at risk for coronary artery disease. (*Level of Evidence: B*)**
6. **Coronary angiography is recommended before a Ross procedure if noninvasive imaging of the coronary arteries is inadequate. (*Level of Evidence: C*)**
7. **A yearly ECG is recommended in young adults less than 30 years of age with mean Doppler gradients greater than 30 mm Hg or peak Doppler gradients greater than 50 mm Hg. (*Level of Evidence: C*)**
8. **An ECG is recommended every other year in young adults less than 30 years of age with mean Doppler gradients less than 30 mm Hg or peak Doppler gradients less than 50 mm Hg. (*Level of Evidence: C*)**

CLASS IIa

1. **In asymptomatic young adults less than 30 years of age, exercise stress testing is reasonable to determine exercise capability, symptoms, and blood pressure response. (*Level of Evidence: C*)**
2. **Exercise stress testing is reasonable for patients with a mean Doppler gradient greater than 30 mm Hg or peak Doppler gradient greater than 50 mm Hg if the patient is interested in athletic participation or if clinical findings differ from noninvasive measurements. (*Level of Evidence: C*)**
3. **Exercise stress testing is reasonable for the evaluation of an asymptomatic young adult with a mean Doppler gradient greater than 40 mm Hg or a peak Doppler gradient greater than 64 mm Hg or when the patient anticipates athletic participation or pregnancy. (*Level of Evidence: C*)**
4. **Dobutamine stress testing can be beneficial in the evaluation of a mild aortic valve gradient in the face of low LV ejection fraction and reduced cardiac output. (*Level of Evidence: C*)**
5. **MRI/CT can be beneficial to add important information about the anatomy of the thoracic aorta. (*Level of Evidence: C*)**
6. **Exercise stress testing can be useful to evaluate blood pressure response or elicit exercise-induced symptoms in asymptomatic older adults with AS. (*Level of Evidence: B*)**

CLASS IIb

1. **Magnetic resonance angiography may be beneficial in quantifying AR when other data are ambiguous or borderline. (*Level of Evidence: C*)**

CLASS III

1. **Exercise stress testing should not be performed in symptomatic patients with AS or those with repolarization abnormality on ECG or systolic dysfunction on echocardiography. (*Level of Evidence: C*)**

6.4.1. Clinical Examination

A delayed carotid upstroke with decreased volume is usual with severe AS. A systolic thrill may be present in the suprasternal notch or at the upper right sternal border. Palpation of the LV impulse may reveal a prominent and sustained apical impulse. A systolic ejection sound is usually present (until the fourth decade, after which calcification may restrict mobility of the cusps), usually loudest at the apex but also radiating to the base. An apical crescendo-decrescendo systolic murmur of AS radiating to the upper right sternal border and over the carotids is characteristic.

In patients with moderate to severe AR and LV enlargement, the apical impulse is displaced laterally and is hyperdynamic. An early diastolic high-pitched murmur of AR is usually loudest along the mid-left sternal border. An AR murmur that is louder at the right sternal border indicates aortic root dilatation.

6.4.2. Electrocardiogram

An ECG may reveal QRS voltage of LV hypertrophy, a left atrial abnormality pattern, and/or ST-T repolarization changes.

6.4.3. Chest X-Ray

The chest x-ray may reveal a prominent right-sided heart–border silhouette of the ascending aorta (if dilated), calcification in the aortic valve (if calcification is present), and a left-sided heart–border silhouette of LV hypertrophy/enlargement.

6.4.4. Echocardiography

The echocardiographic assessment should include valve anatomy and motion; aortic root anatomy and dimensions; LV mass, size/volumes, and function (both systolic and diastolic); and the presence or absence of AR. For AS, the continuity equation should be used in adults to calculate aortic valve area (cm^2), preferably indexed to body surface area (cm^2 per m^2).

The peak instantaneous aortic valve gradient alone may overestimate the severity of AS. The mean Doppler gradient may be more reflective of the peak-to-peak gradient as measured at catheterization that is classically used for clinical decision making. Several different methods for quantification of AR should be used, including pressure half-time, jet width, and degree of proximal descending aortic diastolic flow reversal (337).

6.4.5. Magnetic Resonance Imaging/Computed Tomography

MRI/magnetic resonance angiography or CT is valuable in evaluating anatomy of the entire aorta to quantify AR in borderline cases.

6.4.6. Stress Testing

Selective use of exercise stress testing to assess blood pressure and heart rate response, rhythm disorders, and ST-T segment changes may be warranted. The prognostic value of exercise-induced ST depression and T-wave inversion is age dependent, because 80% of adults with AS will have ST depression without prognostic significance. On the other hand, ST-T changes in an adolescent or young adult with exercise may be indications for intervention. The use of stress echocardiography to assess aortic valve area and gradient, LV ejection fraction, and LV volume response may be helpful. The selective use of dobutamine stress echocardiographic studies has been valuable in low-gradient AS with low LV ejection fractions, a situation that is uncommon in adolescents with AS or AR but may be present in older adults with concomitant myocardial or coronary artery disease.

6.4.7. Cardiac Catheterization

Diagnostic catheterization is used selectively when the clinical and echocardiography-Doppler data are incongruent or as a prelude to catheter or surgical intervention. In many laboratories, it is used primarily for the assessment of

preoperative coronary anatomy in males greater than 35 years of age or those with other risk factors for atherosclerosis.

6.5. Problems and Pitfalls

Problems and pitfalls regarding BAV stenosis include the following:

- The click murmur of a BAV may be misdiagnosed as mitral valve prolapse.
- A systolic murmur may be thought to be "benign" because an ejection click is not recognized.
- To quantify the severity of valvular AS by echocardiography-Doppler, mean gradient and aortic valve area should be used rather than relying only on peak systolic gradient, which may overestimate the severity of stenosis. The aortic valve area should be indexed to body surface area to correct for different body sizes and habitus.
- Progressive aortic dilatation may occur in patients with BAV even in the absence of significant AS or AR.
- In the presence of increased LV dimensions and normal wall thickness, an increased LV mass is present. LV mass calculations are needed and should be indexed to body surface area (338).

6.6. Management Strategies for Left Ventricular Outflow Tract Obstruction and Associated Lesions

6.6.1. Recommendations for Medical Therapy

CLASS IIa

1. **It is reasonable to treat systemic hypertension in patients with AS while monitoring diastolic blood pressure to avoid reducing coronary perfusion. (*Level of Evidence: C*)**
2. **It is reasonable to administer beta blockers in patients with BAV and aortic root dilatation. (*Level of Evidence: C*)**
3. **It is reasonable to use long-term vasodilator therapy in patients with AR and systemic hypertension while carefully monitoring diastolic blood pressure to avoid reducing coronary perfusion. (*Level of Evidence: C*)**

CLASS IIb

1. **It may be reasonable to treat patients with BAV and risk factors for atherosclerosis with statins with the aim of slowing down degenerative changes in the aortic valve and preventing atherosclerosis. (*Level of Evidence: C*)**

CLASS III

1. **Vasodilator therapy is not indicated for long-term therapy in AR for the following:**
   a. **The asymptomatic patient with only mild to moderate AR and normal LV function. (*Level of Evidence: B*)**
   b. **The asymptomatic patient with LV systolic dysfunction who is otherwise a candidate for AVR. (*Level of Evidence: B*)**
   c. **The asymptomatic patient with either LV systolic function or mild to moderate LV diastolic dysfunction who is otherwise a candidate for AVR. (*Level of Evidence: C*)**

There are currently no established medical treatments proven to alter the natural history or halt the progression of stenosis in BAV disease (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information). Beta blockers may be administered to delay or prevent aortic root dilatation or progression, but benefit has only been validated in patients with Marfan syndrome or acute aortic dissections. Judicious afterload reduction in patients with hypertension to reduce systolic blood pressure and lower LV wall tension may delay onset of LV dilatation or dysfunction but should be balanced against the risk of reducing diastolic coronary perfusion. There is no clear evidence that afterload reduction decreases the volume of AR or reduces the need for AVR (339). Multimodality molecular imaging has identified proteolytic and osteogenic activity in early aortic valve disease, a precursor to atherosclerotic and calcific degenerative AS (340). Thus, statins may slow the progression of acquired or calcific degenerative AS and probably have a role in treatment of BAV disease early in the process, before significant calcification and AS or AR have developed (341). Although no clinical trials have confirmed the benefits of statins in BAV disease, it appears reasonable to treat those patients who have risk factors for atherosclerosis.

6.6.2. Catheter and Surgical Intervention

In adults with AS, intervention for significant disease usually involves AVR or Ross repair; however, selected adolescents and young adults may benefit from percutaneous balloon valvuloplasty. This technique should be performed at centers with appropriate experience and expertise (112).

6.6.2.1. Recommendations for Catheter Interventions for Adults With Valvular Aortic Stenosis

CLASS I

1. **In young adults and others without significantly calcified aortic valves and no AR, aortic balloon valvotomy is indicated in the following patients:**
   a. **Those with symptoms of angina, syncope, dyspnea on exertion, and peak-to-peak gradients at catheterization greater than 50 mm Hg. (*Level of Evidence: C*)**
   b. **Asymptomatic adolescents or young adults who demonstrate ST or T-wave abnormalities in the left precordial leads on ECG at rest or with exercise and a peak-to-peak catheter gradient greater than 60 mm Hg. (*Level of Evidence: C*)**

CLASS IIa

1. **Aortic balloon valvotomy is reasonable in the asymptomatic adolescent or young adult with AS and a peak-to-peak gradient on catheterization greater than 50 mm Hg when the patient is interested in playing competitive sports or becoming pregnant. (*Level of Evidence: C*)**

CLASS IIb

1. **Aortic balloon valvotomy may be considered as a bridge to surgery in hemodynamically unstable adults with AS, adults at high risk for AVR, or when AVR cannot be performed secondary to significant comorbidities. (*Level of Evidence: C*)**

CLASS III

1. **In older adults, aortic balloon valvotomy is not recommended as an alternative to AVR, although certain younger patients may be an exception and should be referred to a center with experience in aortic balloon valvuloplasties. (*Level of Evidence: B*)**

2. **In asymptomatic adolescents and young adults, aortic balloon valvotomy should not be performed with a peak-to-peak gradient less than 40 mm Hg without symptoms or ECG changes. (*Level of Evidence: B*)**

When valvular AS is secondary to bicuspid commissural fusion, especially in young adults, the potential exists for successful balloon dilation with gradient reduction and extended freedom from reintervention (320). Increasing calcification, with concomitantly increasing transvalvular gradient with increasing patient age, limits results in older adults, in whom AVR is the intervention of choice (320). Criteria for intervention vary, with typical indications including a valve area less than or equal to 0.45 cm^2 per m^2 (if not indexed, 0.8 cm^2 for an average-sized adult with a height of 1.7 m^2), especially in the setting of symptoms of dyspnea, angina, or syncope or with worsening ventricular function. Balloon valvuloplasty may be considered in younger patients in whom there is a need to have augmented cardiac output, such as those with a desire to become pregnant or to participate in vigorous sports. When balloon valvuloplasty is indicated, patients should be referred to a center experienced in the procedure.

6.6.2.2. Recommendations for Aortic Valve Repair/Replacement and Aortic Root Replacement

CLASS I

1. **Aortic valvuloplasty, AVR, or Ross repair is indicated in patients with severe AS or chronic severe AR while they undergo coronary artery bypass grafting, surgery on the aorta, or surgery on other heart valves. (*Level of Evidence: C*)**
2. **AVR is indicated for patients with severe AS and LV dysfunction (LV ejection fraction less than 50%). (*Level of Evidence: C*)**
3. **AVR is indicated in adolescents or young adults with severe AR who have:**
   a. **Development of symptoms. (*Level of Evidence: C*)**
   b. **Development of persistent LV dysfunction (LV ejection fraction less than 50%) or progressive LV dilatation (LV end-diastolic diameter 4 standard deviations above normal). (*Level of Evidence: C*)**
4. **Surgery to repair or replace the ascending aorta in a patient with a BAV is recommended when the ascending aorta diameter is 5.0 cm or more or when there is progressive dilatation at a rate greater than or equal to 5 mm per year. (112) (*Level of Evidence: B*)**

CLASS IIa

1. **AVR is reasonable for asymptomatic patients with severe AR and normal systolic function (ejection fraction greater than 50%) but with severe LV dilatation (LV end-diastolic diameter greater than 75 mm or end-systolic dimension greater than 55 mm*). (*Level of Evidence: B*)**
2. **Surgical aortic valve repair or replacement is reasonable in patients with moderate AS undergoing coronary artery bypass grafting or other cardiac or aortic root surgery. (*Level of Evidence: B*)**

*Consider lower threshold values for patients of small stature of either gender.

CLASS IIb

1. **AVR may be considered for asymptomatic patients with any of the following indications:**
   a. **Severe AS and abnormal response to exercise. (*Level of Evidence: C*)**
   b. **Evidence of rapid progression of AS or AR. (*Level of Evidence: C*)**
   c. **Mild AS while undergoing coronary artery bypass grafting or other cardiac surgery and evidence of a calcific aortic valve. (*Level of Evidence: C*)**
   d. **Extremely severe AS (aortic valve area less than 0.6 cm and/or mean Doppler systolic AV gradient greater than 60 mm Hg) in an otherwise good operative candidate. (*Level of Evidence: C*)**
   e. **Moderate AR undergoing coronary artery bypass grafting or other cardiac surgery. (*Level of Evidence: C*)**
   f. **Severe AR with rapidly progressive LV dilation when the degree of LV dilation exceeds an end-diastolic dimension of 70 mm or end-systolic dimension of 50 mm, with declining exercise tolerance, or with abnormal hemodynamic responses to exercise. (*Level of Evidence: C*)**
2. **Surgical repair may be considered in adults with AS or AR and concomitant ascending aortic dilatation (ascending aorta diameter greater than 4.5 cm) coexisting with AS or AR. (*Level of Evidence: B*)**
3. **Early surgical repair may be considered in adults with the following indications:**
   a. **AS and a progressive increase in ascending aortic size. (*Level of Evidence: C*)**
   b. **Mild AR if valve-sparing aortic root replacement is being considered. (*Level of Evidence: C*)**

CLASS III

1. **AVR is not useful for prevention of sudden death in asymptomatic adults with AS who have none of the findings listed under the Class IIa/IIb indications. (*Level of Evidence: B*)**
2. **AVR is not indicated in asymptomatic patients with AR who have normal LV size and function. (*Level of Evidence: B*)**

In adults, surgical AVR or Ross procedure is the primary intervention for aortic valve disease. Complications related to Shones syndrome and multiple levels of obstruction warrant referral to a surgeon with experience in ACHD. Congenital heart surgeons should perform complex operations that involve LVOT obstruction (eg, modified Konno or Konno procedure), and management of these patients should be in a tertiary center with experienced ACHD medical and surgical personnel.

In BAV disease, there is no consensus regarding the specific diameter of the ascending aorta for which replacement is indicated, but greater than or equal to 5 cm has been suggested by some (112). Whether aortic root replacement or wrapping is optimal in such patients is a matter of debate; results of AVR in CHD have an acceptable medium-term result (342). There has been concern about the stability of neoaortic root sizes with the Ross procedure for BAV with a dilated aortic root (322), in part because of data on the free-standing aortic root technique, after which progressive root enlargement and neo-AR have been noted (340). Simon-Kupilik et al (343) reported that by 7 years after the Ross

procedure, only 45% of patients were free of neoaortic autograft dilatation, but 90% had an increase in autograft root dimensions greater than 25%. However, dilatation did not always necessitate reoperation for aneurysm formation or increasing AR (343), and the use of a subcoronary Ross procedure results in stable root dimensions (344,345).

6.7. Recommendations for Key Issues to Evaluate and Follow-Up

CLASS I

1. **Lifelong cardiology follow-up is recommended for all patients with aortic valve disease (AS or AR) (operated or unoperated; refer to Section 6.4, Recommendations for Evaluation of the Unoperated Patient). (*Level of Evidence: A*)**
2. **Serial imaging assessment of aortic root anatomy is recommended for all patients with BAV, regardless of severity. The frequency of imaging would depend on the size of the aorta at initial assessment: if less than 40 mm, it should be reimaged approximately every 2 years; if greater than or equal to 40 mm, it should be reimaged yearly or more often as progression of root dilation warrants or whenever there is a change in clinical symptoms or findings. (*Level of Evidence: B*)**
3. **Prepregnancy counseling is recommended for women with AS who are contemplating pregnancy. (*Level of Evidence: B*)**
4. **Patient referral to a pediatric cardiologist experienced in fetal echocardiography is indicated in the second trimester of pregnancy to search for cardiac defects in the fetus. (*Level of Evidence: C*)**
5. **Women with BAV and ascending aorta diameter greater than 4.5 cm should be counseled about the high risks of pregnancy. (*Level of Evidence: C*)**
6. **Patients with moderate to severe AS should be counseled against participation in competitive athletics and strenuous isometric exercise. (*Level of Evidence: B*)**
7. **Echocardiographic screening for the presence of BAV is recommended for first-degree relatives of patients with BAV. (*Level of Evidence: B*)**

Progressive or recurrent AS, AR, or aortic enlargement may occur in the presence of a BAV. Patients with or without intervention should be followed up at least yearly for symptoms and findings of progressive AS/AR ventricular dysfunction and arrhythmia. This includes resting and stress ECGs to look for ischemic changes or arrhythmia; echocardiography-Doppler to monitor LV size/volume and systolic and diastolic function, aortic valve function, and aortic root size and anatomy; and 24-hour ambulatory ECG monitoring.

With or without intervention, both AS and AR are progressive lesions that may ultimately require surgical intervention. Prosthetic valve complications include endocarditis, thrombosis, periprosthetic regurgitation with or without hemolysis, and obstruction related to pannus in growth. Patients who undergo the Ross procedure (placement of the native pulmonary valve in the aortic position and pulmonary or aortic homograft replacement of the pulmonary valve) are at risk of developing autograft dilatation with progressive neo-AR, right-sided pulmonary homograft obstruction and/or regurgitation, and occasionally myocardial ischemia and/or infarct related to proximal coronary artery obstruction or kinking. Patients who undergo the Bentall procedure (aortic root replacement with a composite valve and graft with coronary reimplantation) are also at risk for proximal coronary obstruction.

Congenital AS with a long-standing significant gradient can be associated with ventricular arrhythmias in adulthood, including the small possibility of sudden cardiac death (346). Patients should be monitored carefully for symptoms and should have regular ECGs, plus periodic ambulatory rhythm monitoring, to assist in early detection of arrhythmias (104,347).

6.7.1. Reproduction

Most pregnancies with congenital AS are uncomplicated, but in those with severe AS, morbidity is higher, although deaths are still rare (348,349). Prepregnancy counseling is recommended. Referral to a fetal cardiologist is indicated in the second trimester because there is an increased risk of transmitting CHD to offspring. Delivery in all but the mildest of cases may be best accomplished at centers experienced with high-risk heart disease. Vaginal delivery is generally preferable to cesarean delivery except in the presence of obstetric contraindications or severe cardiac situations, such as aortic aneurysm, dissection, or critical AS, or in women who are undergoing anticoagulation (because of the risks of intracranial bleeding in the newborn). Delivery may be performed under controlled circumstances at approximately 38 weeks (provided fetal lung maturity is deemed sufficient) with appropriate monitoring of maternal heart rate, blood pressure, and fetal monitoring. Even though the 2007 AHA Scientific Statement on Prevention of Infective Endocarditis does not recommend routine prophylaxis for vaginal delivery or cesarean section, many obstetricians administer antibiotics at the time of rupture of membranes for women with aortic valve disease (74) (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information). Prepregnancy or prenatal evaluation and counseling in women with congenital aortic valve disease is essential to explore options and manage risks. The role of balloon valvuloplasty in the palliation of symptomatic pregnant women with AS requires further study, but it may be applied successfully if symptoms are refractory to medical therapy (348,350). There is no evidence that pregnancy accelerates progression of congenital AS or AR. In some cases, the drop in systemic vascular resistance that accompanies pregnancy may reduce the regurgitant fraction in AR (351).

6.7.2. Activity/Exercise

Patients with moderate to severe AS who participate in competitive athletics risk sudden cardiac death, likely from arrhythmias; therefore, they should be strongly counseled against competitive athletics and strenuous isometric exercise. Patients with aortopathy should be similarly counseled about the risks of chest injury. Exercise and athletics have been addressed in the report of Task Force 2 on CHD of the 36th Bethesda Conference (49).

6.8. Isolated Subaortic Stenosis

6.8.1. Definition

SubAS refers to a discrete fibrous ring or fibromuscular narrowing and is distinct from genetic hypertrophic cardio-

myopathy with dynamic LVOT obstruction. Often, the subaortic fibrous ring may extend onto the anterior mitral leaflet. On occasion, accessory mitral tissue or anomalous chords may cause SubAS. SubAS is usually a solitary congenital defect but may be superimposed on other congenital heart defects (eg, VSD) or acquired under certain circumstances (eg, after VSD patching). Although the obstruction is usually fixed, a secondary dynamic component may develop due to myocardial hypertrophy and dynamic LV ejection.

The prevalence of discrete SubAS among ACHD patients has been reported to be 6.5% (352), with a male preponderance of 2:1. In some cases, such as Shones syndrome, SubAS may be familial.

6.8.2. Associated Lesions

SubAS may occur as an associated defect with VSDs, AVSD, or conotruncal anomalies and may develop after patch closure of a perimembranous or malaligned VSD or AVSD (353).

6.8.3. Clinical Course With/Without Previous Intervention

The course of SubAS is often progressive. The unrepaired history includes progressive aortic valve damage, ventricular dysfunction, IE, and sudden cardiac death. The dominant feature may be obstruction or AR (352,354,355). AR occurs in more than 50% of those with SubAS. Once the peak Doppler gradient across the SubAS is more than 30 mm Hg, and if the membrane is immediately adjacent to the aortic valve or there is extension of the membrane onto the mitral valve, LVOT obstruction is likely to be progressive (354). Once the peak instantaneous Doppler LVOT gradient reaches 50 mm Hg or more, there is increased risk for moderate or severe AR (354). Patients are at risk for endocarditis, which will contribute to worsening AR (356).

6.8.4. Clinical Features and Evaluation

6.8.4.1. Clinical Examination

The murmur of SubAS is crescendo-decrescendo and is present at the apex and over the left parasternal precordium. Transmission into the carotids is inconsistent. In contrast to valvular AS, no ejection click is present. In some patients, a thrill may be present. A high-frequency early diastolic murmur of AR may be heard along the left sternal border.

6.8.4.2. Electrocardiogram

The ECG may be normal if there is no significant AS or AR or may show varying degrees of LV hypertrophy and secondary repolarization abnormalities.

6.8.4.3. Chest X-Ray

The chest x-ray is usually normal unless the development of significant AR results in LV dilatation and/or the ascending aorta.

6.8.4.4. Echocardiography

Transthoracic 2-dimensional echocardiography-Doppler is the initial diagnostic method of choice to precisely characterize LV outflow anatomy, severity of subaortic gradient, associated aortic valve abnormality, degree of AR, diameter of the ascending aorta, and mitral valve involvement, as well as to assess LV hypertrophy and function (systolic and diastolic) in patients suspected of having SubAS. TEE may add valuable anatomic detail, both preoperatively and intraoperatively. Three-dimensional echocardiography may be particularly helpful in demonstrating complex LV outflow anatomy.

6.8.5. Diagnostic Cardiac Catheterization

Noninvasive imaging is usually sufficient for evaluation and monitoring of patients with SubAS. Cardiac catheterization may be indicated when SubAS is associated with other lesions. Accurate measurement of the subvalvular gradient necessitates the use of end-hole or micromanometer-tipped catheters. LV angiography is often unreliable for diagnosis of a discrete subaortic membrane, although carefully angulated views may reveal the membrane.

6.8.6. Problems and Pitfalls

The findings of a discrete fibrous subaortic ring may be subtle on TTE, unless there are good acoustical windows that allow transducer positions perpendicular to the membrane and the LVOT obstruction is examined carefully with color flow Doppler. The degree of SubAS may be underestimated or overestimated in the presence of a VSD, depending on whether the VSD is proximal or distal to the subaortic obstruction.

6.8.7. Management Strategies

6.8.7.1. Medical Therapy

There is no specific medical therapy for SubAS, except endocarditis prophylaxis when there is a prior history of endocarditis (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information).

6.8.7.2. Recommendations for Surgical Intervention

CLASS I

1. **Surgical intervention is recommended for patients with SubAS and a peak instantaneous gradient of 50 mm Hg or a mean gradient of 30 mm Hg on echocardiography-Doppler. (*Level of Evidence: C*)**
2. **Surgical intervention is recommended for SubAS with less than a 50-mm Hg peak or less than a 30-mm Hg mean gradient and progressive AR and an LV dimension at end-systolic diameter of 50 mm or more or LV ejection fraction less than 55%. (*Level of Evidence: C*)**

CLASS IIb

1. **Surgical resection may be considered in patients with a mean gradient of 30 mm Hg, but careful follow-up is required to detect progression of stenosis or AR. (*Level of Evidence: C*)**
2. **Surgical resection may be considered for patients with less than a 50-mm Hg peak gradient or less than a 30-mm Hg mean gradient in the following situations:**
   a. **When LV hypertrophy is present. (*Level of Evidence: C*)**
   b. **When pregnancy is being planned. (*Level of Evidence: C*)**
   c. **When the patient plans to engage in strenuous/competitive sports. (*Level of Evidence: C*)**

CLASS III

1. **Surgical intervention is not recommended to prevent AR for patients with SubAS if the patient has trivial LVOT obstruction or trivial to mild AR. (*Level of Evidence: C*)**

Surgical intervention should be recommended for patients with SubAS when the peak instantaneous echocardiographic gradient is greater than 50 mm Hg, the mean gradient is greater than 30 mm Hg, or catheter measurement of the resting peak-to-peak gradient is greater than 50 mm Hg. Patients with lesser degrees of obstruction may be considered for surgery in the presence of LV systolic dysfunction or significant aortic valve regurgitation or if the patient desires to become pregnant or to participate in active sports.

Patients with peak gradients less than 50 mm Hg and symptoms of breathlessness or fatigability should be investigated with exercise Doppler to determine whether the gradient increases with exertion. The presence of LV systolic dysfunction or a VSD proximal to the SubAS may result in underestimation of obstruction. The value of surgical resection for the sole purpose of preventing progressive AR in patients without other criteria for surgical intervention has not been determined and is an issue about which there is no clear consensus.

Surgical repair of discrete SubAS usually involves circumferential resection of the fibrous ring and some degree of resection of the muscular base along the left septal surface. Potential operative complications include injury to the aortic or mitral valves, complete heart block, or creation of a VSD. Patients with associated AR often undergo valve repair at the time of subaortic resection. Fibromuscular or tunnel-type SubAS is more difficult to palliate surgically and usually involves a more aggressive septal resection and sometimes mitral valve replacement. Patients with SubAS due to severe long-segment LVOT obstruction may require a Konno procedure, which involves an extensive patch augmentation of the LV outflow area to the aortic annulus.

Postoperative complications may include damage to the aortic or mitral valve, heart block, iatrogenic VSD, and IE. SubAS may recur after surgical repair; repair of SubAS in children does not necessarily prevent AR development in adults (352,357). However, data exist to suggest that surgical resection of fixed SubAS before the development of a more than 40-mm Hg LVOT gradient may prevent reoperation and secondary progressive aortic valve disease (358). Although catheter palliation has been performed in some centers on an experimental basis, its efficacy has not been demonstrated (359).

6.8.8. Recommendations for Key Issues to Evaluate and Follow-Up

CLASS I

1. **Lifelong cardiology follow-up, including evaluation by and/or consultation with a cardiologist with expertise in ACHD, is recommended for all patients with SubAS, repaired or not. (*Level of Evidence: C*)**
2. **The unoperated asymptomatic adult with stable LVOT obstruction due to SubAS and a mean gradient less than 30 mm Hg without LV hypertrophy or significant AR should be monitored at yearly intervals for increasing obstruction, the development or progression of AR, and the evaluation of systolic and diastolic LV function. (*Level of Evidence: B*)**

CLASS IIa

1. **Stress testing to determine exercise capability, symptoms, ECG changes or arrhythmias, or increase in LVOT gradient is reasonable in the presence of otherwise equivocal indications for intervention. (*Level of Evidence: C*)**

Progressive and/or recurrent obstruction and progressive AR may occur in patients with or without intervention. Recurrent obstruction is frequent after resection of SubAS and occurs at a rate of approximately 20% over 10 years. In addition, AR may occur despite resection of the subaortic membrane.

6.8.9. Special Issues

6.8.9.1. Pregnancy
Refer to Section 6.7.1, Reproduction.

6.8.9.2. Exercise and Athletics
Refer to Section 6.7.2, Activity/Exercise.

6.9. Supravalvular Aortic Stenosis

6.9.1. Definition

SupraAS is a fixed obstruction that arises from just above the sinus of Valsalva and extends a variable distance along the aorta. The origin of the coronary arteries is usually proximal to the obstruction, which subjects them to high systolic pressure and limited diastolic flow. There may be partial or complete ostial obstruction of the coronary arteries, ectasia, or aneurysm of the coronary arteries (360). Pathological specimens with diffuse or focal intimal and medial fibrosis, hyperplasia, dysplasia, adventitial fibroelastosis, and occasional intramedial dissection have been reported in children and more commonly in adults (361–363). This may produce significant coronary insufficiency and early onset of coronary artery disease in adult life.

6.9.2. Associated Lesions

SupraAS is commonly seen in Williams syndrome and can be associated with hypoplasia of the entire aorta, renal artery stenosis, stenoses of other major aortic branches, and long-segment peripheral pulmonary artery stenosis. Williams syndrome, an autosomal dominant disorder due to an elastin gene mutation, is associated with abnormal (elfin) facies, cognitive and behavioral disorders, and joint abnormalities. Familial non-Williams SubAS is also associated with branch pulmonary artery stenosis and hypoplasia, as well as hypoplastic descending aorta and renal artery stenosis.

6.9.3. Clinical Course (Unrepaired)

Most patients with SupraAS will be followed up from childhood and may present in adult life with symptoms due to significant outflow obstruction, systemic hypertension, or ischemia. Clinical presentation with ischemic symptomatology referable to insufficient coronary artery flow has been reported due to either anatomic obstruction or myocardial hypertrophy that limits nonepicardial coronary flow (364).

6.10. Recommendations for Evaluation of the Unoperated Patient

CLASS I

1. **TTE and/or TEE with Doppler and either MRI or CT should be performed to assess the anatomy of the LVOT, the ascending aorta, coronary artery anatomy and flow, and main and branch pulmonary artery anatomy and flow. (*Level of Evidence: C*)**
2. **Assessment of anatomy and flow in the proximal renal arteries is recommended in ACHD patients with SupraAS. (*Level of Evidence: C*)**
3. **Assessment of systolic and diastolic ventricular function is recommended in ACHD patients with SupraAS. (*Level of Evidence: C*)**
4. **Assessment of aortic and mitral valve anatomy and function is recommended in ACHD patients with SupraAS. (*Level of Evidence: C*)**
5. **Adults with a history or presence of SupraAS should be screened periodically for myocardial ischemia. (*Level of Evidence: C*)**

CLASS IIa

1. **Exercise testing, dobutamine stress testing, positron emission tomography, or stress sestamibi with adenosine studies can be useful to evaluate the adequacy of myocardial perfusion. (*Level of Evidence: C*)**

6.10.1. Clinical Examination

Preferential flow (Coanda effect) up the rightward portion of the ascending aorta into the right brachiocephalic artery may produce discordant amplitude of arterial pulsations in the carotids and upper extremities. There may also be a differential blood pressure between the right and left arm. A systolic thrill in the suprasternal notch is common. There may be a dynamic LV apical impulse. The second heart sound may be narrowly or paradoxically split. A fourth heart sound may be present over the LV apical thrust. An ejection click is absent. There is a crescendo-decrescendo murmur at the cardiac base, with radiation to the right side of the neck. Careful auscultation over the back and flank may reveal murmurs of peripheral pulmonary artery stenosis or renal artery stenosis. Hypertension and an abdominal bruit may signify renal artery stenosis.

6.10.2. Electrocardiogram

The ECG may reveal LV hypertrophy and secondary ST-T–wave abnormalities versus ischemic changes, depending on the severity of LVOT obstruction and the degree of coronary involvement. ST-T–wave changes may not regress after surgery, even if the gradient has been relieved; therefore, it is important to determine whether these postoperative abnormalities are recent versus chronic.

6.10.3. Chest X-Ray

The chest x-ray is often normal but may reveal LV hypertrophy or asymmetry of the aortic knob.

6.10.4. Imaging

TTE and TEE demonstrate the diameter and anatomy of the aortic sinus, sinotubular ridge, and proximal ascending aorta, the origins of the coronary arteries, the systolic gradient across the SupraAS obstruction, and the degree of LV hypertrophy. MRI/CT is required to more precisely define the anatomy of the aorta and branches, as well as the pulmonary arteries. As with any long-segment obstruction, assessment of the gradient can be challenging and may require cardiac catheterization for complete assessment of hemodynamic severity of the stenosis. Patients with Williams syndrome should have imaging of the entire aorta, including the renal arteries, because of the association with arterial stenosis at any level.

6.10.5. Stress Testing

Stress testing may be helpful to assess coronary involvement and LV compensation.

6.10.6. Myocardial Perfusion Imaging

Noninvasive screening for coronary insufficiency may be helpful if there are symptoms or ECG findings of ischemia or if there is significant coronary involvement on imaging studies. Patients with limited cognitive function may be unable to perform maximal stress testing but pharmacological stress (adenosine or dobutamine) nuclear imaging with positron emission tomography, single photon emission computed tomography, or MRI may be performed.

6.10.7. Cardiac Catheterization

Diagnostic catheterization may help to delineate anatomy and accurately measure gradients. Selective coronary angiography should be approached with caution after thorough noninvasive and angiographic examination of the aortic root, because coronary ostial stenosis is a frequent occurrence in this population. Intravascular ultrasonography may provide definition of coronary artery anatomy and define the nature and extent of the diseased vessel before consideration of repair.

6.11. Management Strategies for Supravalvular Left Ventricular Outflow Tract

6.11.1. Recommendations for Interventional and Surgical Therapy

CLASS I

1. **Operative intervention should be performed for patients with supravalvular LVOT obstruction (discrete or diffuse) with symptoms (ie, angina, dyspnea, or syncope) and/or mean gradient greater than 50 mm Hg or peak instantaneous gradient by Doppler echocardiography greater than 70 mm Hg. (*Level of Evidence: B*)**
2. **Surgical repair is recommended for adults with lesser degrees of supravalvular LVOT obstruction and the following indications:**
   a. **Symptoms (ie, angina, dyspnea, or syncope). (*Level of Evidence: B*)**
   b. **LV hypertrophy. (*Level of Evidence: C*)**
   c. **Desire for greater degrees of exercise or a planned pregnancy. (*Level of Evidence: C*)**
   d. **LV systolic dysfunction. (*Level of Evidence: C*)**
3. **Interventions for coronary artery obstruction in patients with SupraAS should be performed in ACHD centers with demonstrated expertise in the interventional management of such patients. (*Level of Evidence: C*)**

Surgical relief of SupraAS is accomplished with the use of complex patching of the aorta, with reconstruction of the coronary ostia or bypass grafting, depending on the anatomy of the lesion. Surgical results with reconstruction of the coronary ostium or bypass grafting, depending on anatomy of the lesions noted, have been described without long-term follow-up (365). Branch pulmonary artery stenosis may be addressed during the same surgical procedure. There are no long-term follow-up data on adults after surgery for SupraAS. Catheter-based techniques have not been described for this lesion.

6.11.2. Recommendations for Key Issues to Evaluate and Follow-Up

CLASS I

1. **Both operated and unoperated patients with SupraAS should be followed up annually at a regional ACHD center. (*Level of Evidence: C*)**
2. **Long-term psychosocial assessment and oversight, including the need for legal guardianship, are recommended for patients with Williams syndrome. (*Level of Evidence: C*)**

Repair of SupraAS results in low early and late mortality and low incidence of recurrent obstruction. The durability of patch material requires long-term observation for assessment of aneurysm formation. Both operated and unoperated patients with SupraAS require lifelong annual follow-up to evaluate the degree of obstruction and LV compensation, the development of coronary insufficiency or systemic hypertension, and the development of mitral regurgitation.

Patients with Williams syndrome require long-term psychosocial follow-up to assess competency for self-care and recommend appropriate measures. This is particularly important because these patients have verbal and social skills that result in an overestimation of their executive functioning.

6.11.3. Special Issues

In SupraAS, abnormal systolic forces on the proximal coronary arteries and ostia may accelerate coronary artery disease, and impaired diastolic coronary filling due to ostial obstruction may cause or augment myocardial ischemia. Care must be taken to avoid circumstances that decrease diastolic pressure so that critical coronary perfusion is maintained.

6.11.4. Exercise and Athletics

Refer to Section 6.7.2, Activity/Exercise.

6.11.5. Recommendations for Reproduction

CLASS I

1. **SupraAS, whether associated with Williams syndrome or nonsyndromic, has a strong likelihood of being an inherited disorder. Undetected family members may be at risk for hypertension, coronary disease, or stroke; therefore, all available relatives should be screened. (*Level of Evidence: C*)**
2. **Patients with SupraAS and significant obstruction, coronary involvement, or aortic disease should be counseled against pregnancy. (*Level of Evidence: C*)**

6.12. Aortic Coarctation

6.12.1. Definition

Discrete coarctation of the aorta consists of short-segment narrowing in the region of the ligamentum arteriosum adjacent to the origin of the left subclavian artery. In some cases, there is also narrowing of the aortic arch or isthmus. Extensive collateral vessels may arise proximal to the obstruction. The presence of abundant collaterals may reduce the gradient across the coarctation and mask the severity of the obstruction. An associated intrinsic abnormality in the aortic wall predisposes to dissection or rupture in the ascending aorta or the area of the coarctation. The adult who had surgical repair of coarctation of the aorta as an infant is more likely to have associated cardiac lesions with BAV, SubAS, VSD, and varying degrees of arch hypoplasia. Residual hemodynamic problems from any of these defects may complicate the clinical course and may require more detailed evaluation and follow-up.

6.12.2. Associated Lesions

Associated lesions include BAV, SubAS, mitral valve abnormalities such as parachute mitral stenosis, VSD, and circle of Willis cerebral artery aneurysm.

6.12.3. Recommendations for Clinical Evaluation and Follow-Up

CLASS I

1. **Every patient with systemic arterial hypertension should have the brachial and femoral pulses palpated simultaneously to assess timing and amplitude evaluation to search for the "brachial-femoral delay" of significant aortic coarctation. Supine bilateral arm (brachial artery) blood pressures and prone right or left supine leg (popliteal artery) blood pressures should be measured to search for differential pressure. (*Level of Evidence: C*)**
2. **Initial imaging and hemodynamic evaluation by TTE, including suprasternal notch acoustic windows, is useful in suspected aortic coarctation. (*Level of Evidence: B*)**
3. **Every patient with coarctation (repaired or not) should have at least 1 cardiovascular MRI or CT scan for complete evaluation of the thoracic aorta and intracranial vessels. (*Level of Evidence: B*)**

Aortic coarctation may be recognized in the adult, usually because of systemic arterial hypertension and discrepant upper- and lower-extremity pulses. Patients may complain of exertional headaches, leg fatigue, or claudication. Occasionally, the patient may come to medical attention because of a murmur due to BAV or VSD.

Unoperated survival averages 35 years of age, with 75% mortality by 46 years of age. Systemic hypertension, accelerated coronary heart disease, stroke, aortic dissection, and congestive heart failure are common complications in patients who have not had surgery or who are operated on in later childhood or adult life. An associated BAV with varying degrees of AS or AR may be present. Death may be related to congestive heart failure, aortic rupture/dissection, endocardi-

tis/endarteritis, intracerebral hemorrhage, or myocardial infarction.

6.13. Clinical Features and Evaluation of Unrepaired Patients

Hypertension is present in the right arm, relative to the lower extremities, unless an anomalous origin of the right subclavian artery is present. The left subclavian artery may be close to the aortic narrowing and thus may or may not be hypertensive. The carotid pulsations may be hyperdynamic. There is a pulse delay between the right arm and the femoral or popliteal arteries. A murmur or bruit may be heard in the left interscapular position, either due to the coarctation or to collaterals. If collateral vessels are present, continuous murmurs may be present over the parasternal areas (mammary arteries) and around the left scapula; occasionally, periscapular collaterals can be palpated. Auscultation should be directed toward detecting a parasternal and apical systolic ejection sound suggestive of an associated BAV with or without a systolic crescendo-decrescendo murmur of LVOT obstruction or an early diastolic decrescendo murmur of AR.

6.13.1. Electrocardiogram

The ECG may demonstrate LV hypertrophy and secondary ST-T–wave abnormalities but occasionally will show RV conduction delay.

6.13.2. Chest X-Ray

An anterior-posterior projection of the chest x-ray may show a prominent curvilinear shadow along the mid-right sternal border that represents a dilated ascending aorta. An indentation at the coarctation site may produce a "3 sign" adjacent to the area beneath the transverse arch and above the main pulmonary artery silhouette. Notching on the underside of the ribs (usually 3 to 9) from collateral vessels may be apparent.

6.13.3. Echocardiography and Doppler

The coarctation may be demonstrated on a suprasternal notch view of the aortic arch and proximal descending aorta, which, when combined with color flow imaging and continuous-wave spectral Doppler interrogation, may demonstrate turbulence in the proximal descending aorta and show the characteristic flow profile of forward diastolic flow. An abnormal Doppler flow pattern may also be noted in the abdominal aorta, ie, decreased pulsatility and absence of early diastolic flow reversal. Abnormal flow in collateral vessels can be detected by color flow and pulse Doppler. It is also important to measure the dimensions of the aortic annulus, aortic sinuses, sinotubular ridge, and ascending aorta. The anatomy of the aortic valve should be determined, as well as LV size, mass, and function. Careful investigation should rule out associated lesions such as VSD, SubAS, and mitral valve deformity.

6.13.4. Stress Testing

In addition to the usual evaluation of exercise capacity and symptoms, rhythm, and ECG response, stress testing goals include assessment of the systemic arterial blood pressure response at rest and with exercise, which is a surrogate evaluation of the coarctation gradient. Stress-echocardiography–Doppler is valuable and is targeted at obtaining the rest and exercise suprasternal notch continuous-wave Doppler coarctation gradient, including the diastolic profile. Arm-leg blood pressure and echocardiography-Doppler gradient assessment during exercise may be problematic and better assessed with supine ergometer stress testing or dobutamine stress testing.

6.13.5. Magnetic Resonance Imaging/Magnetic Resonance Angiography or Computed Tomography With 3-Dimensional Reconstruction

MRI or CT angiography with 3-dimensional reconstruction identifies the precise location and anatomy of the coarctation and entire aorta, as well as collateral vessels (366). Magnetic resonance angiography to search for aneurysms of the intracranial arteries is appropriate. Magnetic resonance angiography may also be useful to quantify collateral flow.

6.13.6. Catheterization Hemodynamics/Angiography

Diagnostic cardiac catheterization is mainly justified when associated coronary artery disease is suspected and surgery is planned; however, MRI/magnetic resonance angiography or CT remains the preferred means of imaging the area of coarctation. Cardiac catheterization is also indicated if catheter-based intervention (angioplasty or stent) is to be performed, and generally, this should be performed only in centers with interventional capability.

6.13.7. Problems and Pitfalls

In the presence of sizable collaterals, femoral pulses may be less diminished, and catheter-based and Doppler systolic gradients may not capture the degree of obstruction of aortic coarctation and hence may be misleading. Repair of coarctation late in childhood or in adult life often does not prevent persistence or late recurrence of systemic hypertension. Hypertension can also reappear several years after coarctation repair.

6.14. Management Strategies for Coarctation of the Aorta

6.14.1. Medical Therapy

Hypertension should be controlled by beta blockers, ACE inhibitors, or angiotensin-receptor blockers as first-line medications. The choice of beta blockers or vasodilators may be influenced in part by the aortic root size, the presence of AR, or both.

6.14.2. Recommendations for Interventional and Surgical Treatment of Coarctation of the Aorta in Adults

CLASS I

1. **Intervention for coarctation is recommended in the following circumstances:**
   a. **Peak-to-peak coarctation gradient greater than or equal to 20 mm Hg. (*Level of Evidence: C*)**
   b. **Peak-to-peak coarctation gradient less than 20 mm Hg in the presence of anatomic imaging evidence of significant coarctation with radiological evidence of significant collateral flow. (*Level of Evidence: C*)**

2. **Choice of percutaneous catheter intervention versus surgical repair of native discrete coarctation should be determined by consultation with a team of ACHD cardiologists, interventionalists, and surgeons at an ACHD center. (*Level of Evidence: C*)**
3. **Percutaneous catheter intervention is indicated for recurrent, discrete coarctation and a peak-to-peak gradient of at least 20 mm Hg. (*Level of Evidence: B*)**
4. **Surgeons with training and expertise in CHD should perform operations for previously repaired coarctation and the following indications:)**
   a. **Long recoarctation segment. (*Level of Evidence: B*)**
   b. **Concomitant hypoplasia of the aortic arch. (*Level of Evidence: B*)**

CLASS IIb

1. **Stent placement for long-segment coarctation may be considered, but the usefulness is not well established, and the long-term efficacy and safety are unknown. (*Level of Evidence: C*)**

The appropriate type of treatment for native coarctation of the aorta in adults remains somewhat controversial. In particular, for women who are or will be of childbearing age after repair, there is a concern about the tissue integrity of the paracoarctation region, particularly during pregnancy. As such, one may select direct surgical repair with excision of the paracoarctation tissue for those individuals. For recurrent aortic coarctation (coarctation after surgical repair), the prevailing opinion now is that catheter-based intervention (balloon or stent) is generally safe and the preferred alternative to surgery in the absence of confounding features (eg, aneurysm or pseudoaneurysm formation, or significant coarctation that affects the adjoining arch arterial branches).

McCrindle et al reported the recurrence rate after balloon angioplasty of primary coarctation in adults at approximately 7%, with a further 7% of patients having a suboptimal primary outcome (367). For localized discrete narrowing, balloon angioplasty is an acceptable alternative to surgical repair as a primary intervention but is still considered less suitable for long-segment or tortuous forms of coarctation.

In the majority of circumstances, discrete recoarctation is managed with balloon dilation with or without stent placement. In many ACHD centers, surgery is reserved for patients who are unsuitable for percutaneous treatment or who have undergone unsuccessful percutaneous treatment.

Reoperation is performed via midline sternotomy or posterolateral thoracotomy, depending on the precise form of repair required for a given individual and whether associated lesions (BAV disease, dilated aortic root) need to be addressed simultaneously. The use of partial or full cardiopulmonary bypass may be required to prevent paralytic complications. Intervention, whether via a catheter approach or surgery, should be done in centers with experience in the medical and surgical care of ACHD patients.

Early mortality is usually less than 1% for primary operation. Early mortality is higher for reoperation (1% to 3%) and can be as high as 5% to 10% if there are significant comorbidities or significant LV dysfunction. Rebound hypertension can occur early after repair and may be prevented or blunted by preoperative administration of a beta blocker. Morbidity in adults with reoperation for coarctation can be considerable and may include significant early postoperative bleeding, pleural effusion, lung contusion, recurrent laryngeal nerve palsy, or phrenic nerve injury (with hemidiaphragmatic paresis or paralysis). Other postoperative complications include recoarctation and hypertension. Aneurysm formation at the repair site can occur after patch aortoplasty (particularly with the use of a Dacron patch) or resection of the coarctation shelf. False aneurysms may also occur at the repair site. Late dissection proximal or distal to the repair site can occur. Paraplegia secondary to spinal cord ischemia is rare but is more common with poor collateral circulation. Arm claudication or subclavian steal syndrome is rare but in particular may occur after use of the subclavian flap technique.

6.14.3. Recommendations for Key Issues to Evaluate and Follow-Up

CLASS I

1. **Lifelong cardiology follow-up is recommended for all patients with aortic coarctation (repaired or not), including an evaluation by or consultation with a cardiologist with expertise in ACHD. (*Level of Evidence: C*)**
2. **Patients who have had surgical repair of coarctation at the aorta or percutaneous intervention for coarctation of the aorta should have at least yearly follow-up. (*Level of Evidence: C*)**
3. **Even if the coarctation repair appears to be satisfactory, late postoperative thoracic aortic imaging should be performed to assess for aortic dilatation or aneurysm formation. (*Level of Evidence: B*)**
4. **Patients should be observed closely for the appearance or reappearance of resting or exercise-induced systemic arterial hypertension, which should be treated aggressively after recoarctation is excluded. (*Level of Evidence: B*)**
5. **Evaluation of the coarctation repair site by MRI/CT should be performed at intervals of 5 years or less, depending on the specific anatomic findings before and after repair. (*Level of Evidence: C*)**

CLASS IIb

1. **Routine exercise testing may be performed at intervals determined by consultation with the regional ACHD center. (*Level of Evidence: C*)**

All patients with either interventional catheterization or surgical repair of coarctation of the aorta should have close follow-up and aggressive management of blood pressure and other risk factors for cardiovascular disease. This should include at least yearly cardiology evaluations. Consultation with a cardiologist with special expertise in ACHD should be obtained on initial contact to determine risk factors specific for the patient's anatomy and the presence of associated lesions. Evaluation of the repair site by MRI/CT should be repeated at intervals of 5 years or less, depending on the specific anatomic findings before and after repair. Consideration should be given to cumulative lifetime radiation exposure with multiple CT examinations.

6.14.4. Exercise and Athletics

Exercise and athletics have been addressed recently by the 36th Bethesda Conference (49). Significant residual or unre-

paired coarctation, associated BAV with AS, or a dilated aortic root warrants prohibition of contact sports, isometric or heavy weight lifting, and sudden stop-start sports. It would be prudent to have a cardiology consultation, stress testing, and an echocardiogram before permitting low- to moderate-level dynamic sports or light weight lifting.

6.14.5. Reproduction

Pregnancy in coarctation of the aorta continues to be a source of concern, but major cardiovascular complications are infrequent (368). An assessment of the hemodynamic status, severity of coarctation, and associated lesions, particularly BAV, AS, or a significantly dilated root, should be undertaken before pregnancy for proper planning and advice. The potential for aortic dissection remains, although it is quite small unless the aorta is dilated significantly.

6.14.6. Endocarditis Prophylaxis

Patients with uncomplicated native coarctation or uncomplicated, recurrent coarctation that is successfully repaired do not require endocarditis prophylaxis unless there is a prior history of endocarditis or a conduit has been inserted or if surgical repair or stenting has been performed less than 6 months previously (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information).

7. Right Ventricular Outflow Tract Obstruction

7.1. Definition

Obstruction to the RVOT in the adult patient can be either congenital or acquired. Table 13 summarizes the various forms.

Congenital obstruction can be at the pulmonary valve, below the pulmonary valve, or above the pulmonary valve. Below the pulmonary valve, obstruction can be either at the infundibular or the subinfundibular level. Infundibular stenosis is a crucial component of tetralogy of Fallot (369). Other congenital forms of infundibular stenosis include reactive myocardial hypertrophy that is secondary to pulmonary valvular stenosis or, much less commonly, stenosis of the ostium of the infundibulum itself. Case reports of other causes include a pouch of accessory tricuspid valve tissue or an accessory tricuspid valve leaflet (370), fibrous tags from the valve openings of the inferior vena cava or coronary sinus that obstruct the RVOT (371), and aneurysms of either the aortic sinus of Valsalva (372,373) or the membranous interventricular septum (374).

Subinfundibular stenosis or double-chambered right ventricle is a rare form of outflow obstruction that results in the RV being divided into a high-pressure inlet portion and a low-pressure outlet portion by a thick muscle bundle, the hypertrophied septoparietal trabeculation, an anomalous apical shelf, or an abnormal moderator band (375,376). The degree of obstruction can vary widely, and an associated VSD is common.

The sequelae from surgical intervention may also result in stenosis, at times requiring reintervention. Postoperatively, valvular or conduit stenosis and regurgitation of implanted bioprosthetic pulmonary valves placed during childhood are expected outcomes for many patients when they reach adulthood. Pulmonary valve and trunk stenosis of the pulmonary homograft in patients undergoing the Ross procedure has been a particularly difficult problem, seen in up to 20% of patients in some series (377). Postoperative conduit stenosis and regurgitation are also major issues for patients with tetralogy of Fallot.

Table 13. Types of Right Ventricular Outflow Tract Obstruction in Adults

Congenital
Valvular
Dome-shaped pulmonic valve
Dysplastic pulmonary valve
Unicuspid or bicuspid pulmonary valve
Infundibular stenosis, usually associated with tetralogy of Fallot
Associated with pulmonic stenosis, hypertrophic cardiomyopathy
Infundibular obstruction other than muscular
Tricuspid valve tissue
Fibrous tags from inferior vena cava or coronary sinus
Aneurysm of the sinus of Valsalva
Aneurysm of the membranous septum
Subinfundibular obstruction
Double-chambered right ventricle
Supravalvular stenosis
Hourglass deformity at valve
Pulmonary artery membrane
Pulmonary artery stenosis
Peripheral pulmonary artery stenosis
Associations: Rubella, Alagille, Williams, Keutel syndromes
Postoperative
Valvular
Native valve restenosis
Prosthetic valve stenosis
Conduit stenosis
Peripheral stenosis after prior arterial shunt procedure to pulmonary arteries

7.2. Associated Lesions

Pulmonary valvular, subvalvular, or supravalvular stenosis may be an associated lesion in many patients with other forms of complex CHD. In addition, a markedly dilated pulmonary main trunk consistent with a low-pressure pulmonary artery aneurysm may be present and is occasionally seen with PS. These large main pulmonary artery aneurysms may achieve considerable size and may appear as a mediastinal mass on chest x-ray. They are usually asymptomatic, but in rare situations, they compress contiguous areas such as the left main coronary artery and then cause chest pain. Rupture is extremely rare in these low-pressure, highly elastic vessels, and so, in and of themselves, they do not require intervention (378). This is in marked contrast to hypertensive pulmonary aneurysms, which may rupture.

7.3. Valvular Pulmonary Stenosis

7.3.1. Definition

Valvular PS is usually an isolated lesion, occurs in approximately 7% to 12% of all CHD, and accounts for 80% to 90% of all lesions that cause RVOT obstruction (379). Its inheritance rate is low, ranging from 1.7% to 3.6% (380,381). Approximately 20% of patients with valvular PS have a dysplastic valve (382,383), and if part of Noonan syndrome, these patients have an autosomal dominant trait with variable penetrance that has been mapped to chromosome 12 (384,385).

There are 3 morphological types of clinical significance.

1. The typical dome-shaped pulmonary valve is characterized by a narrow central opening but a preserved, mobile valve mechanism. Three rudimentary raphes are usually present, but clear-cut commissures are not identifiable. The pulmonary trunk is dilated, mostly owing to an inherent medial abnormality. The jet from the stenotic valve tends to favor flow to the left pulmonary arterial branch. Calcification of the valve is occasionally seen in older adult patients.
2. The dysplastic pulmonary valve is less common. The leaflets are poorly mobile, and there is marked myxomatous thickening with no commissural fusion. The pulmonary annulus and the outflow tract may also be narrowed. The lesion is a frequent component of the Noonan syndrome.
3. The unicuspid or bicuspid pulmonary valve is generally a feature of tetralogy of Fallot. It may or may not create significant obstruction itself.

PS is considered mild when the peak gradient across the valve is less than 30 mm Hg, moderate when the gradient is 30 to 50 mm Hg, and severe when the gradient is greater than 50 mm Hg.

7.4. Clinical Course

7.4.1. Unrepaired Patients

Valvular PS usually presents with an asymptomatic systolic murmur, but occasionally, a patient will present with exercise intolerance. Stenosis is rarely progressive when the initial gradient is mild, but moderate PS can progress owing to progressive valve stenosis or reactive hypertrophy of the infundibulum.

The outcome of medically managed patients with PS was discussed in the Second Natural History Study (104). Patients with peak-to-peak catheterization-derived gradients greater than 80 mm Hg underwent pulmonary valvotomy. Patients with gradients greater than 50 mm Hg clearly did worse than those with gradients less than 50 mm Hg (104).

7.4.2. Noonan Syndrome Patients With Prior Repair

For the most part, the clinical issues regarding when to intervene in the postoperative patient are similar to those for patients before surgery. The main difference is in the presence of valvular regurgitation. In low-pressure pulmonary regurgitation (mean pulmonary artery pressure less than 20 mm Hg), the diastolic gradient between the RV and pulmonary artery may be quite small, and significant pulmonary regurgitation may be difficult to detect. Restenosis after percutaneous valvuloplasty is more common if a residual gradient greater than 30 mm Hg remains immediately after the procedure. A dilated pulmonary artery may not decrease in size after pulmonary valve intervention.

7.5. Recommendations for Evaluation of the Unoperated Patient

CLASS I

1. **Two-dimensional echocardiography-Doppler, chest x-ray, and ECG are recommended for the initial evaluation of patients with valvular PS. (*Level of Evidence: C*)**
2. **A follow-up physical examination, echocardiography-Doppler, and ECG are recommended at 5-year intervals in the asymptomatic patient with a peak instantaneous valvular gradient by Doppler less than 30 mm Hg. (*Level of Evidence: C*)**
3. **A follow-up echocardiography-Doppler is recommended every 2 to 5 years in the asymptomatic patient with a peak instantaneous valvular gradient by Doppler greater than 30 mm Hg. (*Level of Evidence: C*)**

CLASS III

1. **Cardiac catheterization is unnecessary for diagnosis of valvular PS and should be used only when percutaneous catheter intervention is contemplated. (*Level of Evidence: C*)**

7.5.1. Clinical Examination

Most adult patients with PS are normal in appearance. In the Noonan syndrome, there is characteristically short stature, webbed neck, hypertelorism, lymphedema, low-set ears and hairlines, hyperelastic skin, chest deformities (eg, flat, pectus excavatum or pectus carinatum), and micrognathia (383). Approximately one third of Noonan patients are mentally disabled, and cryptorchidism is common.

The cardiac examination of a patient with PS is dependent on the severity of stenosis, the pathology of the valve, and any associated cardiac lesions. The physical examination in mild PS is characterized by a normal jugular venous pulse, no RV lift, and a pulmonary ejection sound that tends to decrease with inspiration. It is the only right-sided auscultatory event that decreases with inspiration (owing to premature opening of the pulmonary valve by the atrial kick into the stiff RV). A pulmonary ejection murmur that increases with inspiration is usually heard ending in mid systole. In severe PS, there is usually an elevated jugular venous pressure with a prominent "A" wave. An RV lift is common, and there is a much louder and longer pulmonary ejection murmur with loss of the ejection sound. Wide splitting of S_2 may be present, and P_2 may be reduced or absent. A right-sided S_4 may also be heard. Evidence for right-sided heart failure is uncommon until late in the disease process.

7.5.2. Electrocardiogram

The ECG is usually normal when the RV systolic pressure is less than 60 mm Hg, but more severe obstruction leads to right atrial enlargement, right-axis deviation, and RV hypertrophy (386).

7.5.3. Chest X-Ray

The heart size on chest x-ray is normal unless there is an associated cardiac lesion. Vascular fullness in the left lung

base greater than the right base (Chen's sign) is due to the preferential pulmonary flow to the left lung in patients with PS (387). Dilatation of the main pulmonary artery is common in doming PS but not in dysplastic PS. Calcification of the valve may rarely be seen in older patients. The right atrium may be enlarged.

7.5.4. Echocardiography

TTE is generally definitive, but in some patients, TEE may better define the anatomy of the RVOT. A Doppler gradient is readily determined and is used to define when to intervene. Pulmonary valve mobility can also be assessed, along with the presence of other cardiac lesions, and RV function can be semiquantified. Saline microcavitations can help define any right-to-left shunt due to a PFO. When the PS is severe, systolic interventricular septal flattening may be present. In patients with a dysplastic pulmonary valve, the valve can be seen to be thickened and immobile, with the absence of poststenotic dilation of the main pulmonary artery. Evidence of pulmonary regurgitation should be sought by Doppler examination.

7.5.5. Magnetic Resonance Imaging/ Computed Tomography

In uncomplicated valvular PS, the use of MRI or CT is simply confirmatory. These studies do provide excellent imaging of the main, branch, and peripheral pulmonary arteries and are useful when these associated lesions are of concern or to assess the degree of pulmonary regurgitation or TR.

7.5.6. Cardiac Catheterization

Cardiac catheterization is rarely necessary for diagnosis. Gradients above, at, and below the pulmonic valve should be obtained. A peak RV systolic pressure of less than 35 mm Hg and a systolic pulmonary valve gradient of less than 10 mm Hg are considered the upper limits of normal. RV angiography helps define contractile function, the presence of infundibular obstruction, and mobility of the pulmonary valve. Angiography of the pulmonary artery can assess the degree of pulmonary regurgitation and any stenotic lesions in the main, branch, or peripheral pulmonary arteries.

There is little progression in PS severity when the gradient is less than 30 mm Hg; such patients can be followed up at least every 5 years with a clinical examination and Doppler echocardiogram. Those with more significant stenosis should be followed up on a yearly basis. Most patients with PS who reach adulthood are asymptomatic and require no specific therapy. If a dynamic outflow tract obstruction exists, therapy with drugs that slow the heart rate and improve diastolic filling time (ie, beta blockers) (388) and those that might potentially reduce the systolic gradient and improve lusitropy (ie, calcium channel blockers and disopyramide) may also be used clinically, in a manner similar to that in patients with hypertrophic cardiomyopathy and other diseases of LV diastolic dysfunction. Elevated right-sided heart pressures, edema, and ascites can be treated with thiazides, loop diuretics, and aldosterone antagonists as appropriate.

7.5.7. Relationship Between Peak Instantaneous Doppler Echocardiographic Pressure Gradients and Peak-to-Peak Cardiac Catheterization Gradients

The 2006 ACC/AHA valvular heart disease guidelines and much of the older literature used the catheter-derived peak-to-peak gradient across the pulmonary valve to determine when to intervene in valvular PS (112). Patients with valvular PS do not require cardiac catheterization for diagnosis, however, and the relationship between the peak-to-peak invasive hemodynamic gradient and the Doppler peak instantaneous gradient becomes relevant in deciding appropriateness for invasive evaluation and intervention. There are recent data that suggest the peak-to-peak gradient by cardiac catheterization correlates best with the mean Doppler (and not peak instantaneous Doppler) gradient in this situation (389) and that the peak instantaneous gradient systematically overestimates the peak-to-peak cardiac catheterization gradient by slightly more than 20 mm Hg. Correlation of the echocardiography-Doppler gradient with other clinical findings is important.

7.6. Problems and Pitfalls

In the adult, the symptoms related to PS may be confused with a variety of other conditions that need to be considered. Some of these are noted below. A pulmonary velocity of up to 2.5 m per s may be detected by echocardiography-Doppler in patients with an ASD or pulmonary regurgitation. This relates only to increased flow across the pulmonary valve and does not imply coexistent PS.

7.6.1. Dyspnea

Dyspnea occurs in patients with severe PS. Whenever symptoms do not match the severity of the anatomy (ie, symptoms with a PS gradient less than 50 mm Hg or no symptoms and a severe PS gradient), exercise studies are often helpful in assessment of functional capacity. A determination of maximal oxygen consumption along with exercise duration is also useful.

7.6.2. Chest Pain

In the older patient or one with multiple risk factors for coronary artery disease, if angina-type symptoms are present, a stress imaging study should be done to help screen for functional coronary artery disease. Markedly enlarged pulmonary artery aneurysms may rarely cause chest pain by compression of the left main coronary artery.

7.6.3. Enlarging Right Ventricle

Progressive RV dilation in patients with PS suggests an associated lesion such as ASD. In the postoperative patient, this may imply restenosis or pulmonary regurgitation. The severity of low-pressure pulmonary regurgitation may be difficult to diagnose clinically or by echocardiography, because the RV end-diastolic pressure may be only a few millimeters of mercury below the pulmonary arterial end-diastolic pressure. This results in a minor diastolic gradient that is difficult to detect by auscultation and color Doppler because the flow is laminar. Occasionally, imaging with MRI or pulmonary angiography may be required.

7.6.4. Pulmonary Arterial Hypertension

Patients with isolated valvular PS are not expected to have PAH. If evidence of PAH is present, then other causes must be considered, such as associated peripheral pulmonary artery stenosis. Patients who had a systemic–to–pulmonary artery shunt as a child may have branch pulmonary artery stenosis at the site of the anastomosis. In some postoperative patients, repair of the PS may have been only part of a larger surgical procedure that included a late VSD closure or patent ductus repair, and pulmonary vascular disease may now complicate the clinical picture.

7.6.5. Cyanosis

Cyanosis is usually not part of RVOT lesions, unless there is an associated ASD or a substantial increase in right atrial pressure and right-to-left shunting through a PFO. Otherwise, one should seek an alternative source of the cyanosis.

7.6.6. Systemic Venous Congestion

The presence of systemic venous congestion suggests significant RV dysfunction and is an uncommon finding in isolated PS. Exceptions occasionally seen in adults are those patients with cor pulmonale due to intrinsic lung disease or to left-sided heart disease, those with constrictive pericarditis or a restrictive cardiomyopathy, and those with severe TR due to other causes (eg, endocarditis, percutaneous pacemaker, or Ebstein's anomaly). These diagnoses must be excluded before the right-sided heart failure is attributed to PS.

7.7. Management Strategies

There is no specific medical therapy for valvular PS. If right-sided heart failure occurs, it is treated primarily with diuretics. There are few data to support the efficacy of digoxin in this circumstance. Patients with atrial arrhythmias often require either antiarrhythmic therapy, ablation, or both. Sudden death is very rare (390). The treatment of significant PS is either by percutaneous balloon valvuloplasty or by surgical intervention.

7.7.1. Recommendations for Intervention in Patients With Valvular Pulmonary Stenosis

CLASS I

1. **Balloon valvotomy is recommended for asymptomatic patients with a domed pulmonary valve and a peak instantaneous Doppler gradient greater than 60 mm Hg or a mean Doppler gradient greater than 40 mm Hg (in association with less than moderate pulmonic valve regurgitation). (*Level of Evidence: B*)**
2. **Balloon valvotomy is recommended for symptomatic patients with a domed pulmonary valve and a peak instantaneous Doppler gradient greater than 50 mm Hg or a mean Doppler gradient greater than 30 mm Hg (in association with less than moderate pulmonic regurgitation). (*Level of Evidence: C*)**
3. **Surgical therapy is recommended for patients with severe PS and an associated hypoplastic pulmonary annulus, severe pulmonary regurgitation, subvalvular PS, or supravalvular PS. Surgery is also preferred for most dysplastic pulmonary valves and when there is associated severe TR or the need for a surgical Maze procedure. (*Level of Evidence: C*)**
4. **Surgeons with training and expertise in CHD should perform operations for the RVOT and pulmonary valve. (*Level of Evidence: B*)**

CLASS IIb

1. **Balloon valvotomy may be reasonable in asymptomatic patients with a dysplastic pulmonary valve and a peak instantaneous gradient by Doppler greater than 60 mm Hg or a mean Doppler gradient greater than 40 mm Hg. (*Level of Evidence: C*)**
2. **Balloon valvotomy may be reasonable in selected symptomatic patients with a dysplastic pulmonary valve and peak instantaneous gradient by Doppler greater than 50 mm Hg or a mean Doppler gradient greater than 30 mm Hg. (*Level of Evidence: C*)**

CLASS III

1. **Balloon valvotomy is not recommended for asymptomatic patients with a peak instantaneous gradient by Doppler less than 50 mm Hg in the presence of normal cardiac output. (*Level of Evidence: C*)**
2. **Balloon valvotomy is not recommended for symptomatic patients with PS and severe pulmonary regurgitation. (*Level of Evidence: C*)**
3. **Balloon valvotomy is not recommended for symptomatic patients with a peak instantaneous gradient by Doppler less than 30 mm Hg. (*Level of Evidence: C*)**

7.7.2. Percutaneous Balloon Pulmonary Valvotomy

Since the initial successful report of percutaneous balloon valvotomy for pulmonary valve stenosis in 1982 (391), the procedure has evolved to become the treatment of choice for patients with classic domed valvular PS. Balloon valvotomy produces relief of the gradient by commissural splitting. As might be expected from the morphology, results in patients with a dysplastic pulmonary valve are less impressive. In the Valvuloplasty and Angioplasty of Congenital Anomalies (VACA) registry, in 784 cases, the mean transvalvular gradient declined from 71 to 28 mm Hg in patients with typical PS and from 79 to 49 mm Hg in patients with a dysplastic valve (392).

The procedure is usually performed from the right femoral vein. Because of the elasticity of the pulmonary annulus, it has been found that oversizing the balloons up to 1.4 times the measured pulmonary annulus is more effective in achieving a successful result (usually defined by a final valvular gradient of less than 20 mm Hg). To accomplish this oversizing in adults, a double-balloon procedure is frequently used. In general, acute complications from the procedure have been minimal. During the acute performance of the valvotomy, vagal symptoms predominate, along with catheter-induced ventricular ectopy and occasionally right bundle-branch block. Other complications include pulmonary valve regurgitation, pulmonary edema (presumably from increasing pulmonary blood flow to previously underperfused lungs), cardiac perforation and tamponade, high-grade AV nodal block, and transient RVOT obstruction. The latter is sometimes referred to as a "suicidal right ventricle" and is due to abrupt infundibular obstruction once the pulmonary valve obstruction has been relieved (393). This may be alleviated by volume expansion and beta blockade. This postprocedural infundibular obstruction tends to regress over time.

7.7.3. Surgical Pulmonary Valvotomy or Valve Replacement

In 1948, the first pulmonary valve commissurotomies were reported by Sellors (394). Varco introduced the technique of "blind" pulmonary valvotomy in 1951 (395), although better results were found with direct visualization and open techniques quickly became the norm. In patients with a dysplastic valve, partial or total valvectomy was required, and often, a transannular patch was needed owing to annular or pulmonary trunk hypoplasia. Residual pulmonary valve regurgitation is commonplace with all these procedures (396), and late pulmonary valve replacement is often necessary decades later.

In patients with PS and significant valvular regurgitation, valve replacement may be required. Mechanical valve replacement (397) is rarely used because of concerns regarding thrombosis and the potential need for measurement of pulmonary pressures; mechanical PVR can be considered in selected patients who have had multiple previous operations and are undergoing warfarin therapy because of another mechanical valve prosthesis. Owing to low pulmonary artery pressure and slow flow despite anticoagulation, there is a high risk of valve thrombosis with mechanical prosthetic valves in the pulmonary position. Bioprosthetic valves (398) can be effectively implanted with good durability in patients of all ages, although valvular degeneration eventually ensues in all. The bovine jugular vein valved xenograft has also been used with good early but mixed late results (399). Although pulmonary homograft replacement (398) is a popular means of surgical reconstruction in children, it has limited durability in the adult patient, especially in the setting of elevated pulmonary artery pressures. Stenosis of the pulmonary homograft has been a particular issue in patients undergoing the Ross procedure (400).

In patients with a markedly dilated main pulmonary artery associated with PS, there are no guidelines to suggest a particular size that requires operative intervention. Because these are low-pressure aneurysms that rarely, if ever, rupture, the decision to intervene surgically is usually a function of whether they are symptomatic, are compressing contiguous structures, or are associated with pulmonary regurgitation and subsequent right ventricle enlargement (378). In these patients, reduction pulmonary arterioplasty or main pulmonary artery replacement with a tube graft or valved tube graft can be accomplished.

Early mortality for isolated pulmonary valve operation is approximately 1% in children. There are no comparable adult data. Freedom from reoperation for bioprosthetic valve deterioration is approximately 90% at 10 years. Residual obstruction may progress. Pulmonary regurgitation may occur; progression of pulmonary regurgitation may eventually necessitate pulmonary valve replacement. Late survival is similar to that of an age-matched population when valvular RVOT obstruction occurs as an isolated lesion.

7.8. Recommendation for Clinical Evaluation and Follow-Up After Intervention

CLASS I

1. **Periodic clinical follow-up is recommended for all patients after surgical or balloon pulmonary valvotomy, with specific attention given to the degree of pulmonary regurgitation; RV pressure, size, and function; and TR. The frequency of follow-up should be determined by the severity of hemodynamic abnormalities but should be at least every 5 years. (*Level of Evidence: C*)**

The murmur of pulmonary regurgitation is easily missed on clinical examination, because it is soft and often short owing to the rapid equilibration of pulmonary artery diastolic pressure with the diastolic pressure in the right ventricle. It may be missed on echocardiography because of minimal turbulence and only small pressure differences between the right ventricle and the pulmonary artery. After pulmonary valvuloplasty the heart size should be normal on chest x-ray. A progressively increasing heart size should prompt the search for pulmonary regurgitation or another lesion. The development of atrial arrhythmias should also prompt a search for residual hemodynamic lesions such as pulmonary regurgitation.

Long-term follow-up data for percutaneous balloon pulmonary valvotomy are now available for up to 10 years. In one representative study (401), mean follow-up of 6.4 plus or minus 3.4 years was available in 62 patients. Some persistent pulmonary regurgitation was present in 39%, and the restenosis (greater than 35 mm Hg at follow-up) rate was only 4.8%. In a smaller study in adults (402) followed up for 4.5 to 9 years, no restenosis was reported in 24 patients after the gradient was reduced from 82 plus or minus 29 mm Hg to 37 plus or minus 14 mm Hg by the acute procedure. In another report of 127 adult patients without valve dysplasia, excellent results were also observed, with a residual gradient primarily found only in those patients who had an inadequate initial result (403). In the VACA registry (404), follow-up data were available on 533 patients a mean of 8.7 years after valvotomy. A suboptimal result (defined as gradient greater than 35 mm Hg at the end of the procedure) was present in 23%. Valve morphology and annulus size were the most significant predictors of long-term results. Pulmonary regurgitation was more commonly seen when the balloon-to-annulus ratio exceeded 1.4, which suggests an optimal ratio of 1.2 to 1.4. Subjective grades of pulmonary regurgitation reported included the following: none (26%), trivial (22%), mild (45%), moderate (7%), and severe (0%). Failure of the original procedure to reduce the gradient significantly also predicted poor long-term success. When restenosis does occur after percutaneous balloon pulmonary valvotomy, it appears that a repeat procedure is effective in patients without dysplastic pulmonary valves (405). Several studies have been reported that compared balloon valvotomy with matched surgical control patients (392,406,407).

In 1 study (406), gradients were slightly but statistically higher in the post–balloon valvotomy group than in the surgical cohort (24 plus or minus 2.7 versus 16 plus or minus 1.5 mm Hg). Pulmonary regurgitation, however, was absent (55%) or mild (45%) in the valvuloplasty group yet at least mild (45%) or moderate (45%) in the surgical cohort. Ventricular ectopy was also much more common in the surgical group (70% versus 5%). Thus, overall results were more favorable in the balloon valvotomy group.

Percutaneous balloon valvotomy thus appears to be an excellent alternative to surgical valvuloplasty or valve replacement in most patients with classic, doming, valvular PS. Its use in patients with a dysplastic valve is much less established, although several authors have suggested situations wherein it may be feasible (408,409). Postoperative valvular, conduit, or homograft stenosis contributes to the causes of clinical RVOT obstruction, with valvular degeneration expected after approximately 10 to 12 years (410). There are some data showing that porcine valves may outlast homografts in children (411). After surgical valvotomy, pulmonary regurgitation is common, and after 3 to 4 decades, RV dysfunction and secondary TR may ensue, necessitating pulmonary valve replacement in some patients. This should be undertaken before there is severe RV enlargement and any more than mild RV dysfunction. Deteriorating exercise capacity or the onset of atrial or ventricular arrhythmias is also a sign of the need for pulmonary valve replacement. This emphasizes the need for lifelong follow-up in such patients (412).

7.8.1. Reproduction

Pregnancy is well tolerated unless the lesion is extremely severe. Percutaneous valvotomy can be performed during pregnancy if necessary, although the need is unusual.

7.8.2. Endocarditis Prophylaxis

Pulmonary valve endocarditis is very rare, and endocarditis prophylaxis is not recommended (413) (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information).

7.8.3. Exercise and Athletics

The 1986 AHA committee report (414) recommends no restriction of activity with mild PS and nonstrenuous exercise with moderate PS; it restricts only those with severe PS. For the competitive athlete, the special ACC Task Force report (415) recommends that PS patients with peak gradients less than 50 mm Hg may participate in all competitive sports, although those with more severe PS should participate only in low-intensity sports.

7.9. Right-Sided Heart Obstruction Due to Supravalvular, Branch, and Peripheral Pulmonary Artery Stenosis

7.9.1. Definition and Associated Lesions

Abnormal narrowing of the main pulmonary artery, the major pulmonary arterial branches, and the peripheral pulmonary arteries can all lead to obstruction of RV outflow. Supravalvular PS or pulmonary arterial stenosis is caused by narrowing of the main pulmonary trunk, the pulmonary arterial bifurcation, or the primary and/or intrapulmonary branches. One variant, the hourglass pattern, is similar to SupraAS and is technically a form of valvular PS, because it is due to stenosis at the commissural ridge of the valve (416). The other pulmonary supravalvular lesions are in the main branches or more peripheral and range from single focal lesions to diffuse hypoplastic ones to frank occlusion; they may be secondary to previous placement of a pulmonary artery band. The pulmonary arterial segments distal to patent stenotic lesions often exhibit poststenotic dilation. Membranous forms of obstruction both above and below the pulmonary valve have also been described. Central and peripheral pulmonary artery stenosis may be a major cardiovascular feature in the Alagille and Keutel syndromes (417–421). Pulmonary artery stenoses are also sequelae of the congenital Rubella syndrome, Williams syndrome, or scarring at the site of a previous pulmonary artery band or aorticopulmonary shunt. These lesions appear pathologically as areas of fibrous intimal proliferation with varying degrees of medial hyperplasia and loss of elastic fibers in the affected areas. The lesions can be single or multiple, and their severity can range from mild valvular stenosis to complete occlusion. Similar lesions have been reported in patients with systemic vasculitis, such as Behcet or Takayasu arteritis, and in patients with Ehlers-Danlos and Silver syndrome. Owing to the normally low vascular resistance present in the pulmonary circuit, a great deal of vascular obstruction is required to result in PAH. Despite the fact that it is unclear what severity of stenosis is truly flow-limiting in the pulmonary arteries, most clinicians define an angiographically significant lesion to be greater than 50% diameter narrowing. These significant lesions would be expected to have a pressure gradient across them and to result in hypertension in the more proximal pulmonary artery.

7.9.2. Clinical Course

Peripheral pulmonary artery stenoses tend to occur in multiple tertiary branches of the pulmonary tree and are progressive; by the time patients are seen as adults, there may be considerable loss of lung parenchyma due to totally occluded segmental pulmonary arteries. With PAH, pulmonary valve regurgitation may be expected.

7.10. Clinical Features and Evaluation of the Unrepaired Patient

The clinical symptom complex is similar to that of valvular PS. Dyspnea and chest pain are uncommon. In severe cases, RV dilation and associated TR may occur. Most patients seen in adulthood are patients referred for suspected primary PAH or chronic pulmonary thromboembolic disease. In the evaluation of a patient with suspected PAH, the presence of peripheral bruits over the back or on either lateral side of the chest during auscultation should raise the suspicion of peripheral PS. These pulmonary vascular bruits are usually systolic only but may be continuous and increase with inspiration. Cyanosis may appear if elevated right atrial pressures result in right-to-left shunting across a PFO.

Findings of certain syndromes should raise suspicion for the presence of pulmonary vessel stenotic lesions. The sequelae of the congenital Rubella syndrome consist of cataracts, deafness, hypotonia, retinopathy, dermatoglyphic abnormalities, and mental disability (422), and PS and peripheral PS are not uncommon.

The Alagille syndrome is an autosomal dominant disorder also called arteriohepatic dysplasia. The prominent features include deep-set eyes, a small pointed chin, and a prominent overhanging forehead (419). Abnormalities of the liver, heart,

eyes, kidney, and skeleton occur, and peripheral PS frequently accompanies the disorder.

The Williams syndrome phenotype has micrognathia, a large mouth and lips, an upturned nose, hypertelorism, malformed teeth, broad forehead, and baggy cheeks (420). SupraAS coexists with peripheral PS.

The Keutel syndrome (423) consists of diffuse calcification of the cartilage, short stubby fingers (brachytelephalangism), hearing loss, and peripheral PS. It is a rare disorder believed to be autosomal recessive in its inheritance pattern.

7.10.1. Electrocardiogram

ECG criteria for RV hypertrophy with strain and right-axis deviation are commonplace in the adult and are related to the severity of the lesion and the RV systolic pressure.

7.10.2. Chest X-Ray

The lung fields on chest x-ray may reveal varying shadows of poststenotic peripheral arterial dilatations in patients with peripheral PS.

7.10.3. Echocardiography

TTE-Doppler helps confirm the presence of RV systolic hypertension and any pulmonary valve regurgitation. Echocardiography may also be able to define proximal pulmonary branch stenosis. It is of much less value in the identification of peripheral PS. TEE is likewise useful only when there are proximal pulmonary artery lesions. Radionuclide studies reveal the severity of peripheral PS in different lung segments.

7.10.4. Magnetic Resonance Imaging/ Computed Tomography

Cardiac MRI with pulmonary angiography and CT are much superior to echocardiography-Doppler for imaging these lesions, and both can help confirm the diagnosis.

7.10.5. Cardiac Catheterization

Cardiac catheterization with contrast angiography is definitive and provides additional information regarding the extent of these lesions, the angiographic severity, the pressure drop across the lesions, and the degree of any associated PAH.

7.11. Recommendations for Evaluation of Patients With Supravalvular, Branch, and Peripheral Pulmonary Stenosis

CLASS I

1. **Patients with suspected supravalvular, branch, or peripheral PS should have baseline imaging with echocardiography-Doppler plus 1 of the following: MRI angiography, CT angiography, or contrast angiography. (*Level of Evidence: C*)**
2. **Once the diagnosis is established, follow-up echocardiography-Doppler to assess RV systolic pressure should be performed periodically, depending on severity. (*Level of Evidence: C*)**

7.11.1. Problems and Pitfalls

Patients with peripheral PS lesions may present with what appears to be a functional precordial murmur. Auscultation over the lung fields should reveal the characteristic vascular bruits. Many patients are asymptomatic. More often in adults, the patient presents with dyspnea of unknown origin. Elevated RV systolic pressure identified by echocardiography should prompt a search for causes of PAH that include collagen vascular disease, portal hypertension, human immunodeficiency virus, use of anorexigens, veno-occlusive disease, sleep apnea, chronic obstructive pulmonary disease, and sarcoidosis (424).

7.11.2. Management Strategies

7.11.2.1. Medical Therapy

Because these supravalvular lesions are mechanical obstructions, there are no effective medical therapies, except for the treatment of right-sided heart failure when it occurs. However, there are interventional therapies that may be attempted.

7.12. Recommendations for Interventional Therapy in the Management of Branch and Peripheral Pulmonary Stenosis

CLASS I

1. **Percutaneous interventional therapy is recommended as the treatment of choice in the management of appropriate focal branch and/or peripheral pulmonary artery stenosis with greater than 50% diameter narrowing, an elevated RV systolic pressure greater than 50 mm Hg, and/or symptoms. (*Level of Evidence: B*)**
2. **In patients with the above indications for intervention, surgeons with training and expertise in CHD should perform operations for management of branch pulmonary artery stenosis not anatomically amenable to percutaneous interventional therapy. (*Level of Evidence: B*)**

Branch pulmonary artery stenosis and/or hypoplasia may be associated with a variety of cardiac malformations or may be a residual from prior surgical intervention, such as an anastomotic lesion at the distal site of a prior Blalock-Taussig or Potts shunt procedure. Surgical exposure to these areas is often difficult, which favors attempts at percutaneous approaches. In some series, the acute success rate—defined as an increase of greater than 50% of predilation vessel diameter or a 20% decrease in systolic RV–to–aortic systolic pressure ratio (425)—has been as high as 60% initially. Complications have included arterial rupture, unilateral or segmental edema, thrombosis, and hemoptysis. In some instances, higher-pressure balloon inflations have improved results.

The highly elastic pulmonary arteries have proved resilient to balloon procedures, and angioplasty methods have generally given way to stent procedures in which there appears to be a higher initial success rate and a lower intermediate-term incidence of restenosis (426). When restenosis does occur, it may respond to redilation. Stents have proved effective compared with either percutaneous angioplasty or surgical intervention in this situation. Stenting of branch PS has also been used in the operating room as adjunctive therapy.

The use of balloon angioplasty and stenting may also be applied to more distal peripheral PS, although the results have generally been less impressive than with branch stenosis (427). Although initial angiographic results from stenting in this situation often appear encouraging, there are currently

inadequate data to recommend the routine use of percutaneous intervention for patients with distal peripheral PS. Surgical intervention with patch enlargement is feasible for supravalvular PS when an oval patch is used (428), and more proximal branch stenosis may also be approached surgically if the vessel is of adequate size. More peripheral stenotic segments cannot usually be corrected with surgery. At times, the only alternative for patients with severe peripheral PS associated with major loss of lung parenchyma is lung transplantation.

7.12.1. Recommendations for Evaluation and Follow-Up

CLASS I

1. **Patients with peripheral PS should be followed up every 1 to 2 years, on the basis of severity, with a clinical evaluation and echocardiography-Doppler to evaluate RV systolic pressure and RV function. (*Level of Evidence: C*)**
2. **Discussion with a cardiac surgeon with expertise in CHD should take place before percutaneous peripheral pulmonary artery interventions are undertaken. (*Level of Evidence: C*)**

The lesions in peripheral PS may be progressive, so patients should be followed up every 1 to 2 years with echocardiography-Doppler to assess RV peak systolic pressure and function. If symptoms recur, then reimaging of the pulmonary arteries is required to assess whether restenosis has occurred and whether further intervention is feasible. Restenosis of these lesions is common, and repeat percutaneous angioplasty, stenting, or surgical intervention may be required when this occurs. When questions arise, consultation between the interventionalist and a congenital heart surgeon is necessary to determine the best approach.

7.13. Right-Sided Heart Obstruction Due to Stenotic Right Ventricular–Pulmonary Artery Conduits or Bioprosthetic Valves

7.13.1. Definition and Associated Lesions

Some gradient is to be expected across any RV–pulmonary artery conduit or any bioprosthetic valve placed in the RVOT. A variety of conduit types have been used in the RVOT, some with valvular tissue and some without. Pulmonary homografts have now come into widespread use, although bioprosthetic (porcine or pericardial) pulmonary valve replacements are still performed. Several groups have also reported experience with use of the valved bovine jugular venous conduit (Contegra), although some issues regarding stenosis at the distal pulmonary site have been noted (429). The normal gradient anticipated across the various prosthetic valves is dependent on the valve size and the flow across the valve. Associated pulmonary regurgitation increases the gradient. A recent review from the American Society of Echocardiography outlines the normally expected Doppler gradients for all prosthetic valves (430) and takes into account the type of valve and the size. Stenosis of the RV–pulmonary artery conduit or any bioprosthetic valve in this position may be graded with the peak Doppler gradient, with a 50-mm Hg gradient considered severe stenosis. This would be expected to result in an RV systolic pressure equal to or greater than 75 mm Hg. In children and young adults, a ratio of RV systolic to LV systolic pressure greater than 0.67 is another parameter for defining a severe lesion. In older adults, the systemic resistance is much higher than in children, and the use of this ratio has been less helpful.

7.13.2 Recommendation for Evaluation and Follow-Up After Right Ventricular–Pulmonary Artery Conduit or Prosthetic Valve

CLASS I

1. **After surgical relief of RVOT obstruction with a conduit or prosthetic valve, patients should be followed up on a 1- to 2-year basis with echocardiography-Doppler assessment of RV systolic pressure and function, as well as a measurement of the gradient across the RVOT. (*Level of Evidence: C*)**

7.13.3. Clinical Examination

A precordial systolic murmur that transmits to the back is an important sign of conduit obstruction. The pulmonary closure sound is usually inaudible. In patients with significant RV obstruction, jugular venous distension with a prominent A wave may be appreciated.

7.13.4. Electrocardiogram

Because all bioprosthetic valves and conduit valves eventually degenerate, both pulmonary regurgitation and stenosis will ensue. As with many lesions that result in RV pressure or volume overload, the ECG may reflect RV hypertrophy or any associated arrhythmias.

7.13.5. Chest X-Ray

The chest x-ray may reveal an enlarging right side of the heart or calcification within the valve or conduit.

7.13.6. Echocardiography

TTE and Doppler are particularly helpful in delineating hemodynamics and facilitate measurement of RV pressure, RV size and function, and gradient across the conduit and prosthetic valve; however, tubular narrowing in a conduit is often associated with underestimation of the gradient.

7.13.7. Magnetic Resonance Imaging/ Computed Tomography

CT and MRI can be used to help define lesion severity and may demonstrate conduit adherence to the sternum, something of interest to the surgeon if a reoperation is contemplated.

7.13.8. Cardiac Catheterization

Because distal conduit stenosis is frequent, cardiac catheterization and angiography in addition to CT and MRI can define the level and severity of stenosis.

7.14. Recommendations for Reintervention in Patients With Right Ventricular–Pulmonary Artery Conduit or Bioprosthetic Pulmonary Valve Stenosis

CLASS I

1. **Surgeons with training and expertise in CHD should perform operations for patients with severe pulmonary prosthetic valve**

stenosis (peak gradient greater than 50 mm Hg) or conduit regurgitation and any of the following:

a. Decreased exercise capacity. (*Level of Evidence: C*)

b. Depressed RV function. (*Level of Evidence: C*)

c. At least moderately enlarged RV end-diastolic size. (*Level of Evidence: C*)

d. At least moderate TR. (*Level of Evidence: C*)

CLASS IIa

1. Either surgical or percutaneous therapy can be useful in symptomatic patients with discrete RV–pulmonary artery conduit obstructive lesions with greater than 50% diameter narrowing or when a bioprosthetic pulmonary valve has a peak gradient by Doppler greater than 50 mm Hg or a mean gradient greater than 30 mm Hg. (*Level of Evidence: C*)

2. Either surgical or percutaneous therapy can be useful in asymptomatic patients when a pulmonary bioprosthetic valve has a peak Doppler gradient greater than 50 mm Hg. (*Level of Evidence: C*)

CLASS IIb

1. Surgical intervention may be considered preferable to percutaneous catheter intervention when an associated Maze procedure is being considered for the treatment of atrial arrhythmia. (*Level of Evidence: C*)

7.14.1. Medical Therapy

Medical management of symptomatic patients with residual or recurrent RVOT obstruction is limited to diuresis and is generally ineffective. There are no effective preventative treatments.

7.14.2. Interventional Catheterization

Both angioplasty and stenting have been applied to obstruction in an RV–to–pulmonary artery conduit. Such cases can present difficult issues, and the decision to proceed with a percutaneous intervention should be made in association with an ACHD surgeon or an ACHD interventionalist. Several investigators have reported success in reducing gradients in RV–to–pulmonary artery conduits or bioprostheses using balloon dilation (431,432), stenting, or percutaneous valve replacement (431–433). The value of these options often depends on whether a discrete obstruction occurs at the stenotic conduit valve or is the result of conduit compression between the sternum and heart, intimal peel formation, or obstruction at the ventricular anastomosis. Obstruction of the distal end of the conduit may be amenable to percutaneous balloon intervention in which the procedure may be useful as a temporary palliation that allows postponement of surgical intervention (434).

A potential alternative to either balloon dilation or stenting in conduit obstruction has been presented recently by Bonhoeffer et al (435), wherein pulmonary valves have been implanted percutaneously within the stenotic conduit. The authors used a bovine jugular venous valve mounted onto a balloon-expandable stent for percutaneous placement. Although the procedure is investigational, it appears quite possible that this approach will evolve to provide an excellent option for the therapy of conduit stenosis and regurgitation. The procedural concept has yet to be proven in larger clinical trials and has yet to be shown to be effective in patients with native valvular PS or regurgitation.

7.14.3. Surgical Intervention

Surgical intervention is generally required once there is evidence of important RV enlargement or the development of significant TR. Because of the complexity of these procedures at times, surgical intervention should be done by a team with specific expertise in ACHD issues.

7.14.4. Key Issues to Evaluate and Follow-Up

Most patients are not limited physically unless the gradient across the conduits or prosthetic valves is greater than 50 mm Hg. Pregnancy is well tolerated unless RV failure is a major issue. Much as with postprocedural valvular PS, the degree of obstruction and the severity of the pulmonary regurgitation determine the frequency of follow-up and the necessary studies. For asymptomatic patients with RV pulmonary artery conduits (with or without a valve) and for those with prosthetic pulmonary valves, regular follow-up with echocardiography-Doppler is usually sufficient. Endocarditis prophylaxis is recommended for patients with a prosthetic pulmonary valve or conduit (refer to Section 1.6, Recommendations for Infective Endocarditis).

7.15. Double-Chambered Right Ventricle

7.15.1. Definition and Associated Lesions

In patients with a double-chambered right ventricle, the right ventricle is divided into a higher-pressure proximal chamber and lower-pressure distal chamber by anomalous myocardial muscle bundles. The morphological features may be very diverse and may involve an anomalous septoparietal band, an anomalous apical shelf, or an abnormal moderator band (376). The distance between the moderator band and the pulmonary artery may be abnormally short (436).

Although the anatomic substrate is congenital, the degree of RVOT obstruction is progressive over time. In approximately three fourths of cases, the VSD is below (proximal to) the level of the midventricular obstruction. Complete or partial spontaneous closure of the VSD can produce worsening RV outflow obstruction and dysfunction. Other associations include valvular PS, tetralogy of Fallot, and double-outlet right ventricle. Unlike tetralogy of Fallot, there is also subaortic obstruction in a number of these patients. The anomaly is uncommon and occurs in approximately 1% of patients with CHD (437). No genetic pattern has been identified, although it has been reported to develop in approximately 3% of patients with repaired tetralogy of Fallot and 3% to 10% of patients with an isolated VSD (438,439).

7.15.2. Clinical Features and Evaluation of the Unoperated Patient

Although most patients undergo repair before adulthood, some present much later. Symptoms in the adult may mimic coronary disease (angina) or LV dysfunction (dyspnea). Occasionally, dizziness and syncope may occur. Some patients are recognized because of the increasing intensity of a systolic murmur, previously ascribed to a small VSD or functional murmur.

7.15.3. Clinical Examination

If midventricular obstruction is marked, the resulting hypertrophy results in an RV heave, and the murmur across the obstruction is harsh, increases with inspiration, and may be accompanied by a palpable thrill. The murmur of an associated VSD may be evident if present. If there is an associated interatrial connection, or the VSD is proximal to the obstruction, cyanosis may occur. Rarely, RV failure and TR develop as the obstruction progresses. In 1 study of patients without repair, the midventricular gradients increased an average of 6.2 plus or minus 3 mm Hg each year (440).

7.15.4. Electrocardiogram

The ECG usually suggests RV hypertrophy. Right-sided leads may help confirm the diagnosis, with upright T waves in V_3R in 40% of the patients tested (441).

7.15.5. Echocardiography-Doppler Imaging

The TTE is diagnostic, with demonstration of the hypertrophy and Doppler/color flow evidence of midventricular gradient. The VSD may be noted. TEE is not usually necessary for the diagnosis.

7.15.6. Magnetic Resonance Imaging

In addition to TTE, MRI is the most useful imaging modality for defining the anatomy (442).

7.15.7. Cardiac Catheterization

Cardiac catheterization and angiography are confirmatory and provide relevant imaging and hemodynamic and shunt information but are rarely necessary to establish the diagnosis.

7.16. Problems and Pitfalls

7.16.1. Multiple Levels of Right Ventricular Outflow Tract Obstruction

As noted previously, RVOT obstruction can occur at multiple levels that can exist simultaneously. The peak RV systolic pressure, as estimated by echocardiography-Doppler via the TR jet, may be the result of more than 1 level of obstruction; therefore, it is important to investigate this possibility thoroughly before surgical intervention is considered. This is particularly important in the adult, in whom prior surgical procedures and other causes of PAH may complicate the clinical picture.

7.17. Management Strategies

7.17.1. Recommendations for Intervention in Patients With Double-Chambered Right Ventricle

CLASS I

1. **Surgery is recommended for patients with a peak midventricular gradient by Doppler greater than 60 mm Hg or a mean Doppler gradient greater than 40 mm Hg, regardless of symptoms. (*Level of Evidence: B*)**

CLASS IIb

1. **Symptomatic patients with a peak midventricular gradient by Doppler greater than 50 mm Hg or a mean Doppler gradient greater than 30 mm Hg may be considered for surgical resection if no other cause of symptoms can be discerned. (*Level of Evidence: C*)**

Echocardiography or cardiac MRI should be used for follow-up. In patients with anginal symptoms, cardiac catheterization to exclude coronary disease may be warranted. Because there may be some dynamic obstruction contributing to the gradient, beta blockers and calcium channel blockers may be tried, but there are few data as to the effectiveness of any medical intervention, and significant (greater than 60-mm Hg peak Doppler gradient) stenosis should be treated with surgical resection.

Isolated case reports of the use of percutaneous balloon techniques, stenting, and alcohol ablation have been reported in patients with subvalvular fibromuscular obstruction, with variable success (443–445). Alcohol ablation of a feeding RV conus branch artery was reported to result in a reduction in the outflow tract gradient. Stenting may also prove to be effective, although stent fracture may occur (446), which raises concerns about stent integrity in the contracting RVOT. Currently, there are no follow-up or comparative results available to suggest any of these percutaneous options are preferable to a surgical approach in these patients.

In patients with double-chambered right ventricle, resection and outflow-enlarging procedures have been very effective, with excellent long-term results (447). Many also require repair of an associated VSD.

7.18. Key Issues to Evaluate and Follow-Up

Most patients do well after surgical intervention of the midventricular obstruction and have few physical limitations. The recurrence of obstruction after adequate surgical repair is quite rare, and follow-up of associated congenital defects usually takes precedence when these patients are reevaluated. There are case reports of patients developing a double-chambered RV after repair of either tetralogy of Fallot (438) or a perimembranous VSD (448). Activity is usually unlimited after surgery. Endocarditis prophylaxis is not recommended (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information).

8. Coronary Artery Abnormalities

8.1. Definition and Associated Lesions

This section includes discussion of patients with acquired coronary anomalies as a result of surgical manipulation of their congenital anomaly, as well as those patients with congenital coronary abnormalities associated with ectopic origins of the coronary arteries.

8.1.1. General Recommendations for Evaluation and Surgical Intervention

CLASS I

1. **Any patient with CHD who has had coronary artery manipulation should be evaluated for coronary artery patency, function, and anatomic integrity at least once in adulthood. (*Level of Evidence: C*)**

2. **Surgeons with training and expertise in CHD should perform operations for the treatment of coronary artery anomalies. (*Level of Evidence: C*)**

Surgical results after the use of reconstruction of the coronary ostium or bypass grafting, depending on anatomy of the lesions noted, have been described, without long-term follow-up (365). In addition to the more commonly noted coronary abnormalities described elsewhere in this section, late development of coronary artery disease that requires revascularization (percutaneous or surgical) has been shown to occur after the Ross procedure, aortic and pulmonary atresia, and Kawasaki disease (449).

8.2. Recommendations for Coronary Anomalies Associated With Supravalvular Aortic Stenosis

CLASS I

1. **Adults with a history or presence of SupraAS should be screened every 1 or 2 years for myocardial ischemia. (*Level of Evidence: C*)**
2. **Interventions for coronary artery obstruction in patients with SupraAS should be performed in ACHD centers with demonstrated expertise in the interventional management of these patients. (*Level of Evidence: C*)**

Although SupraAS may be the least common of the lesions of the LV outflow, lesions may be associated with coronary obstruction from partial to complete ostial obliteration, and patients with these lesions are also at risk for ectasia and aneurysm of the coronary arteries (360). Pathological specimens with diffuse or focal intimal and medial fibrosis, hyperplasia, dysplasia, adventitial fibroelastosis, and occasional intramedial dissection have been reported in children and more commonly in adults (361–363).

8.2.1. Clinical Course (Unrepaired)

Clinical presentation with ischemic symptomatology referable to insufficient coronary artery flow has been reported due to either anatomic obstruction or myocardial hypertrophy that limits nonepicardial coronary flow (364).

8.2.2. Clinical Features

There are no current data describing the incidence of coronary artery symptomatology or outcomes in adults with SupraAS. Nonetheless, given the similarity of pathology to other diffuse coronary arteriopathies, the present writing committee would recommend noninvasive screening for myocardial ischemia in all adults with SupraAS, regardless of repair status. If further definition of coronary artery anatomy were suggested, other imaging modalities such as cardiac catheterization, CT angiography, or intravascular ultrasonography might better define the nature and extent of diseased vessel before consideration of repair.

8.3. Recommendation for Coronary Anomalies Associated With Tetralogy of Fallot

CLASS I

1. **Coronary artery anatomy should be determined before any intervention for RV outflow. (*Level of Evidence: C*)**

Abnormalities seen in CHD include single coronary artery, coronary arteriovenous fistula, intramural coronary artery, supravalvular ridge, accessory left anterior descending coronary artery, and anomalous coronary artery from the pulmonary artery. The most common and important abnormality is the left anterior descending coronary artery arising from the right coronary artery and crossing the RV outflow, which occurs in approximately 3% to 7% of persons with tetralogy of Fallot. The occurrence is more common when the aortic root is more anterior, rightward, or lateral (450).

Given the remarkable survival of adults with tetralogy, it is not of surprise that occurrence of atherosclerotic coronary artery disease has been described (451).

8.3.1. Preintervention Evaluation

Coronary artery origin and course should be delineated before any surgical or interventional procedure, because the potential exists for damage to anomalous coronary arteries to occur during cardiac exposure, surgery on the RVOT, and stenting of RV outflow.

8.3.2. Surgical and Catheterization-Based Interventions

Coronary artery bypass and percutaneous coronary interventions for occurrence of atherosclerotic disease in adults with tetralogy of Fallot have been described (451).

8.4. Recommendation for Coronary Anomalies Associated With Dextro-Transposition of the Great Arteries After Arterial Switch Operation

CLASS I

1. **Adult survivors with dextro-TGA (d-TGA) after ASO should have noninvasive ischemia testing every 3 to 5 years. (*Level of Evidence: C*)**

8.4.1. Definition and Associated Lesions

The coronary artery course plays an important role in the surgical repair of d-TGA. The most common anatomic arrangement occurs in nearly two thirds of patients, with the left coronary artery arising from the anterior facing sinus and the right coronary artery from the posterior facing sinus. Sixteen percent of patients with d-TGA have a circumflex that arises from the right coronary artery, and the remaining patients have inverted coronary artery variants, single coronary arteries, or intramural coronary arteries (452). Damage to the sinus node coronary artery, whether during surgery or during balloon septostomy, has been implicated in the occurrence of atrial arrhythmias and sinus node dysfunction after repair.

8.4.2. Clinical Course

After great artery translocation and transfer of coronary arteries, early and late postoperative loss of coronary perfusion may occur due to causes such as anatomic torsion, extrinsic compression, focal or diffuse fibrocellular intimal thickening, and small-caliber distal coronary arteries with functional decrease in coronary flow reserve (453–455). Survival free of coronary events has been reported as 93%

and 88% at 1 and 15 years, respectively, with many reports associating coronary events with increased mortality (455).

8.4.3. Clinical Features and Evaluation After Arterial Switch Operation

No single ischemia provocation test has been shown to be both sufficiently sensitive and specific to screen for coronary flow abnormalities after a switch repair of d-TGA, and combinations of testing, including echocardiography, nuclear scintigraphy, and exercise testing, have been suggested to improve sensitivity and specificity (455). Given the emergence of an adult population of survivors with d-TGA after ASO, with undefined future course and morbidity, the present writing committee recommends episodic noninvasive ischemia provocation testing every 3 to 5 years. Positive results should be pursued by invasive catheterization with measurement of coronary flow reserve and intravascular ultrasound when appropriate.

8.4.4. Surgical and Catheterization-Based Intervention

Successful surgical, balloon angioplasty, and catheter-based stent revascularizations have been reported after ASO repair for d-TGA (456–458). We recommend that obstructive lesions with associated ischemia or flow abnormalities undergo revascularization appropriate to the lesion.

8.5. Recommendations for Congenital Coronary Anomalies of Ectopic Arterial Origin

CLASS I

1. **The evaluation of individuals who have survived unexplained aborted sudden cardiac death or with unexplained life-threatening arrhythmia, coronary ischemic symptoms, or LV dysfunction should include assessment of coronary artery origins and course. (*Level of Evidence: B*)**
2. **CT or magnetic resonance angiography is useful as the initial screening method in centers with expertise in such imaging. (*Level of Evidence: B*)**
3. **Surgical coronary revascularization should be performed in patients with any of the following indications:**
   a. **Anomalous left main coronary artery coursing between the aorta and pulmonary artery. (*Level of Evidence: B*)**
   b. **Documented coronary ischemia due to coronary compression (when coursing between the great arteries or in intramural fashion). (*Level of Evidence: B*)**
   c. **Anomalous origin of the right coronary artery between aorta and pulmonary artery with evidence of ischemia. (*Level of Evidence: B*)**

CLASS IIa

1. **Surgical coronary revascularization can be beneficial in the setting of documented vascular wall hypoplasia, coronary compression, or documented obstruction to coronary flow, regardless of inability to document coronary ischemia. (*Level of Evidence: C*)**
2. **Delineation of potential mechanisms of flow restriction via intravascular ultrasound can be beneficial in patients with documented anomalous coronary artery origin from the opposite sinus. (*Level of Evidence: C*)**

CLASS IIb

1. **Surgical coronary revascularization may be reasonable in patients with anomalous left anterior descending coronary artery coursing between the aorta and pulmonary artery. (*Level of Evidence: C*)**

8.5.1. Definition, Associated Lesions, and Clinical Course

Congenital anomalous origin of the coronary arteries may occur in 1% to 1.2% of all coronary angiograms performed, with 0.5% of them having the highest-risk lesions of the left main or left anterior descending branch artery arising from the opposite sinus of Valsalva (459). Coronary anomalies account for approximately 15% of sudden cardiac deaths in athletes (potentially due to torsion or slitlike compression of the proximal coronary artery, exercise-induced compression, vasospasm, or ischemic or scar-induced ventricular arrhythmia) (460,461). In 80% of autopsies in athletes with sudden cardiac death and anomalous coronary artery origins, the affected coronary artery coursed between the aorta and the pulmonary artery (461,462).

8.5.2. Clinical Features and Evaluation of the Unoperated Patient

8.5.2.1. Preintervention Evaluation

Patients may present with aborted sudden death, chest pain, arrhythmia, LV dysfunction, or exercise-induced presyncope or syncope. Recently, clinical ischemia provocation screening has been suggested to reduce the global risk of sudden cardiac events in high-risk competitive sports populations; however, individual case reports in which such testing failed to reveal at-risk abnormalities in athletes who later succumbed to sudden coronary death due to anomalous coronary origins highlight the need for further improvement in screening strategies. Visualization of coronary artery course is achieved by CT or MRI (463,464).

To date, anatomic delineation of a coronary artery course between the aorta and pulmonary artery in a young (less than age 50 years) person remains the greatest known risk for an adverse event, with or without symptoms (319). Catheter-based measurement of flow reserve and coronary intravascular ultrasonography have the potential to delineate mechanisms of potential flow obstruction and are increasingly part of diagnostic and therapeutic algorithms (459,465). At present, especially in those younger than age 50 years, this writing committee recommends coronary CT or MRI for more definitive definition of coronary course in persons suspected of having anomalous coronary origins.

8.5.3. Management Strategies

8.5.3.1. Surgical and Catheterization-Based Intervention

Both surgical revascularization (eg, marsupialization, coronary bypass, or coronary reimplantation) and limited cases of

transcatheter stenting have been reported to have short-term stability, without long-term follow-up (466). Coronary bypass grafting is increasingly viewed as a less favorable approach in light of the potential for competitive flow (467).

Surgical revascularization in centers with expertise in the surgical management of anomalous coronary arteries is suggested (319,462,468). Surgical repair is indicated when the left coronary arteries arise from the opposite sinus and course between the aorta and pulmonary artery. Surgical repair is also indicated when the right coronary artery arises from the opposite sinus or courses between the aorta and pulmonary artery in association with concomitant symptoms, or when there is evidence of otherwise unexplained inducible ischemia in these territories (469,470). When the patient has an anomalous right coronary artery and no evidence of ischemia, management is more controversial. A conservative approach in this situation may be reasonable. Given the not uncommon occurrence of anomalous coronary origins and their potential for a devastating outcome, it is imperative that improved data are generated regarding diagnosis, follow-up, and longer-term outcomes.

8.6. Recommendations for Anomalous Left Coronary Artery From the Pulmonary Artery

CLASS I

1. **In patients with an anomalous left coronary artery from the pulmonary artery (ALCAPA), reconstruction of a dual coronary artery supply should be performed. The surgery should be performed by surgeons with training and expertise in CHD at centers with expertise in the management of anomalous coronary artery origins. (*Level of Evidence: C*)**
2. **For adult survivors of ALCAPA repair, clinical evaluation with echocardiography and noninvasive stress testing is indicated every 3 to 5 years. (*Level of Evidence: C*)**

8.6.1. Definition and Associated Lesions and Clinical Course

ALCAPA is relatively rare, occurring in 1 in 300 000 live births. Improved operative revascularization, ensuing myocardial remodeling, and improved medical management of heart failure have increased survival after ALCAPA repair. Similarly, these improvements in care and the recognition of hibernating myocardium have increased the survival of adults with ALCAPA (471). Most adults survive because of collaterals from the right coronary artery, but they may have myocardial ischemia, LV dysfunction, mitral regurgitation, or ventricular arrhythmia. The transition from single to dual coronary surgical repair was performed first by a Takeuchi intrapulmonary arterial baffle; since then, coronary artery reimplantation or coronary bypass grafting has been used for repair (472).

Suprapulmonary arterial stenosis, baffle leaks, and baffle stenosis have all been reported after Takeuchi baffle repair. Late postrepair AR and residual significant mitral valve disease have both been reported. Chest pain, nuclear and positron emission tomography myocardial perfusion abnormalities, and decreased exercise performance have been noted after dual coronary artery repair and may correlate with residual patchy myocardial fibrosis from preoperative ischemia, as well as from residual proximal graft obstruction (473–476). Proximal, midvessel, and even distal coronary artery obstructions, with coronary flow reserve abnormalities, have been noted and treated with intracoronary balloon dilations, stenting, radiotherapy, and reoperation (477–480). There has been no consistent correlation between long-term outcome and late symptoms, noninvasive ischemia and blood flow abnormality testing, residual coronary anatomic or flow abnormalities, or late interventions.

8.7. Management Strategies

8.7.1. Surgical Intervention

If patients present in adulthood with decreased systolic function and previously unrecognized ALCAPA, the present writing committee suggests surgical myocardial revascularization to achieve a dual coronary supply, regardless of myocardial viability testing, given the lack of current data to correlate such testing with outcomes. Given the increasing awareness of residual coronary artery, myocardial, and valvular abnormalities, the present writing committee suggests surveillance with echocardiography and noninvasive ischemia provocation testing every 3 to 5 years for patients after repair of ALCAPA.

8.7.2. Surgical and Catheterization-Based Intervention

Surgical repair by either arterial bypass or, more commonly, reimplantation of the anomalous coronary into the aorta is indicated because of the risk of sudden cardiac death (481,482). If ischemia is demonstrated in patients after repair of ALCAPA with either concomitant symptomatology or echocardiographic changes, the present writing committee recommends invasive catheterization with planned intervention determined by clinical findings.

8.8. Recommendations for Coronary Arteriovenous Fistula

CLASS I

1. **If a continuous murmur is present, its origin should be defined either by echocardiography, MRI, CT angiography, or cardiac catheterization. (*Level of Evidence: C*)**
2. **A large CAVF, regardless of symptomatology, should be closed via either a transcatheter or surgical route after delineation of its course and its potential to fully obliterate the fistula. (*Level of Evidence: C*)**
3. **A small to moderate CAVF in the presence of documented myocardial ischemia, arrhythmia, otherwise unexplained ventricular systolic or diastolic dysfunction or enlargement, or endarteritis should be closed via either a transcatheter or surgical approach after delineation of its course and its potential to fully obliterate the fistula. (*Level of Evidence: C*)**

CLASS IIa

1. **Clinical follow-up with echocardiography every 3 to 5 years can be useful for patients with small, asymptomatic CAVF to exclude development of symptoms or arrhythmias or progression of size or chamber enlargement that might alter management. (*Level of Evidence: C*)**

CLASS III

1. **Patients with small, asymptomatic CAVF should not undergo closure of CAVF. (*Level of Evidence: C*)**

8.8.1. Definition

The development of epicardial and intramural coronary arteries has recently become better understood, with increasing awareness of the vasculogenesis involved in regulation of cell fate, cell migration, transition, and patterning (483). Nonetheless, the present writing committee still has a very primitive understanding of CAVF occurrence and long-term outcomes. The incidence is 0.1% to 0.2% of all catheterized patients, second in frequency of all coronary artery congenital abnormalities to anomalous origin of the coronary arteries (484). Fistulas arise from either or both coronary arteries, with drainage more typically to the right atrium, right ventricle, or right atrial–superior vena cava junction, and occasionally to the coronary sinus or left side of the heart.

8.8.2. Clinical Course

Although the potential for associated myocardial ischemia and infarction, endarteritis, dissection, and rupture has been documented, there are few data associating occurrence, shunt properties, anatomic features, and outcomes. Increasing fistula and shunt size may be associated with increased abnormalities of coronary flow and complications that include chest pain, decreased life expectancy, and risk of rupture (485). Small fistulas may slowly increase in size with advancing age and changes in systemic blood pressure and aortic compliance. Periodic clinical evaluation with imaging such as echocardiography to assess both the size of the fistula and ventricular function is reasonable. Sometimes, small fistulas are detected as an incidental finding on echocardiography.

8.8.3. Preintervention Evaluation

Transcatheter delineation of the CAVF course and access to distal drainage should be performed in all patients with audible continuous murmur and recognition of CAVF.

8.9. Recommendations for Management Strategies

CLASS I

1. **Surgeons with training and expertise in CHD should perform operations for management of patients with CAVF. (*Level of Evidence: C*)**
2. **Transcatheter closure of CAVF should be performed only in centers with expertise in such procedures. (*Level of Evidence: C*)**
3. **Transcatheter delineation of CAVF course and access to distal drainage should be performed in all patients with audible continuous murmur and recognition of CAVF. (*Level of Evidence: C*)**

8.9.1. Surgical Intervention

Surgical fistula closure can be successful if CAVF is well defined and clear surgical access is believed to be technically achievable. Recurrence may be a problem if anatomic definition is suboptimal, and surgery may be difficult to perform owing to poorly visualized, typically distal fistulous connections. Surgical closure of audible CAVF with appropriate anatomy is recommended in all large CAVFs and in small to moderate CAVFs in the presence of symptoms of myocardial ischemia, threatening arrhythmia, unexplained ventricular dysfunction, or left atrial hypertension.

8.9.2. Catheterization-Based Intervention

Numerous reports of transcatheter closure with coils or detachable devices describe near or complete CAVF occlusion in attempted closure procedures (486). Criteria for transcatheter closure of CAVF are similar to those used for surgical closure of CAVF. Transcatheter closure of CAVF should be performed only in centers with particular expertise in such intervention.

8.9.3. Preintervention Evaluation After Surgical or Catheterization-Based Repair

Patients with CAVF, even after repair, may still have large, patulous epicardial conduits. Intermediate- and longer-term follow-up of these thin-walled, ectatic coronary arteries after either surgical or transcatheter repair appears mandated.

9. Pulmonary Hypertension/ Eisenmenger Physiology

9.1. Definition

PAH, a progressive increase in PVR, can lead to subpulmonary ventricular failure and death. PAH can frequently be related to pulmonary venous hypertension (most commonly due to left AV valve disorders, volume excess, or systemic ventricular end-diastolic pressure elevation) and can be classified as World Health Organization PAH class II (due to "left heart disease") with therapies guided toward improving these causes. Within this section, however, the present writing committee will primarily focus on disorders in which PAH is due to other abnormalities and is generally hemodynamically defined as a mean pulmonary artery pressure greater than 25 mm Hg at rest or greater than 30 mm Hg with exercise, pulmonary capillary wedge pressure less than or equal to 15 mm Hg, and PVR greater than 3 mm Hg per L per min per m^2. Idiopathic PAH or PAH of unclear relationship to other diseases is typically a diagnosis of exclusion within the World Health Organization (group I PAH), according to a classification scheme similar to the World Health Organization clinical classification (424). Additional "triggers" for the development of PAH may be present at increased rates in patients with CHD compared with nonaffected individuals. These triggers include but are not restricted to parenchymal and restrictive lung disease, hypoventilation, high altitude, genetic predispositions such as Down syndrome, and left atrial or pulmonary venous hypertension or obstruction. Particular CHD-related PAH (CHD-PAH) occurs in a number of different scenarios, including the following:

a. "Dynamic" PAH related to high shunt flow that responds to reduction of the shunt
b. Immediate postoperative or "reactive" PAH
c. Late, postoperative PAH

d. Secondary to lesions that cause pulmonary venous hypertension
e. Shunt reversal (eg, Eisenmenger physiology).

These guidelines will largely focus on the management of dynamic PAH and Eisenmenger physiology. Recently, CHD-PAH has been recognized to have potentially differing pathogenetic mechanisms, therapeutic goals, treatment plans, and outcomes compared with idiopathic PAH. Hence, during the Third World Symposium on Pulmonary Arterial Hypertension, CHD-PAH was categorized as a unique entity within the more global PAH categorization (group I) (424). Subcategories were also designated on the basis of the complexity and size of the defect, its association with additional extracardiac anomalies, and the status of anatomic repair. More recently, an expansion of the subcategorization has been proposed that allows for further classification based on anatomy (defects above and below the tricuspid valve, as well as clarification of specific types of complex disease), the presence of myocardial restriction (as evidenced by equalization of pressure between chambers), and direction of shunt (left to right, right to left, or balanced) (487).

Congenital heart defects that can lead to PAH are numerous. Unrepaired, large systemic–to–pulmonary artery (left-to-right) shunts, seen in ASD, VSD, AVSD, and PDA, account for most cases of PAH. However, complex lesions such as partial or total anomalous pulmonary venous return, unrepaired or palliated conoventricular defects including truncus arteriosus, or transposition of the great arteries, and single-ventricle variants can also result in the development of PAH. Other causes of PAH may include pulmonary vein stenosis and pulmonary veno-occlusive disease. Over time, with severe vascular changes accompanying a persistent large anatomic shunt, a bidirectional or predominantly right-to-left shunt accompanied with oxygen-unresponsive hypoxemia can ensue, identified as Eisenmenger physiology (488). In patients with large left-to-right shunts or unrepaired complex congenital heart defects, PAH can develop as early as the first decade of life; however, in patients with medium-sized or larger ASDs, Eisenmenger syndrome typically appears later in life and may be recognized first during the changes in hemodynamic loading that occur with pregnancy. Whether additional triggers of PAH other than intravascular shunts are required for development of Eisenmenger syndrome remains debatable.

9.2. Clinical Course

9.2.1. Dynamic Congenital Heart Disease–Pulmonary Arterial Hypertension

The development of CHD-PAH associated with systemic–to–pulmonary artery shunts is dependent on both the type and size of the underlying anatomic defect, as well as the magnitude of shunt flow (shear stress and structural changes lead to intravascular and matrix-dependent inflammatory mediator release and changes). Pulmonary vascular histology resembles that described in idiopathic PAH, with medial thickening and plexiform lesions in severe cases (489). In fact, the hypertensive pulmonary arteriopathy, vasoconstriction, and marked increase in pulmonary ventricular afterload of CHDs was the first model used to assist in the understanding of the vascular and cardiac changes associated with idiopathic PAH (490).

Individuals with an unrepaired truncus arteriosus are at very high risk of developing PAH, whereas those with VSDs and ASDs are at moderate and relatively low risk, respectively. Whether the variation in these risks is related to shunt flow or to an underlying genetic predisposition is unknown. The nature of the anatomic abnormality also determines the age at presentation. Patients with AVSD, truncus arteriosus, transposition of the great vessels, large PDA, and VSD present earliest. Most patients with CHD-PAH have a better prognosis than those with idiopathic PAH.

9.2.2. Immediate Postoperative Congenital Heart Disease–Pulmonary Arterial Hypertension

More commonly reported in children than in ACHD patients, pulmonary vascular reactivity due to perioperative endothelial cell injury may be heightened in the immediate postoperative phase of cardiopulmonary surgery. This can precipitate marked increases in PVR, leading to acute right-sided heart failure with the attendant decrease in cardiac output, systemic hypotension, metabolic acidemia, and right-sided heart ischemia. In addition, airway resistance increases in relation to peribronchial edema and bronchoconstriction, gas exchange suffers, and alveolar edema and cardiovascular collapse may occur in the final stages. Immediate perioperative acute increases in pulmonary resistance that precipitate a "crisis" tend to occur in individuals with more "dynamic" and less "fixed" resistance.

9.2.3. Late Postoperative Congenital Heart Disease–Pulmonary Arterial Hypertension

Typically, late postoperative CHD-PAH is attributed to the timing of anatomic shunt repair that is too late, miscalculation of the likelihood of surgical repair, or the long-standing effects of stable but elevated RV afterload that leads to recalcitrant vascular remodeling. However, when one diagnoses late postoperative CHD-PAH, the multiple additional non–shunt-mediated risk factors (including LV hypertrophy and diastolic dysfunction, valvular abnormalities, pulmonary venous hypertension or obstruction, restrictive or hypoventilatory lung disease, chronic liver disease, and toxin use) that contribute to PAH must be ruled out to target appropriate therapy.

9.2.4. Normal to Mildly Abnormal Pulmonary Vascular Resistance States

Individuals with tricuspid atresia or similar single-ventricle physiologies who undergo surgical creation of cavopulmonary anastomoses (Glenn shunt and its variants or Fontan palliation and its variants) have pulmonary circulation that connects directly to the systemic venous circulation, lacks normal pulsatile flow, and hence depends on low PVR for survival. Because the subpulmonary ventricle has been bypassed, and circulation of blood relies solely on systemic ventricular function, any increase in pulmonary vascular impedance can interfere with LV filling. Thus, maintenance of a low PVR is critically important. Clinical course and

further management strategies are discussed elsewhere in these guidelines.

9.2.5. Eisenmenger Physiology

Similar to patients with idiopathic PAH, dyspnea on exertion is the most common presenting symptom of patients with Eisenmenger physiology, followed by palpitation, edema, volume retention, hemoptysis, syncope, and progressive cyanosis (488). Increasingly through the third decade of life, morbidity becomes substantial in this patient population. Eisenmenger patients have additional complications compared with patients with idiopathic or other forms of secondary PAH. Hypoxemia-related secondary erythrocytosis leads to increased blood viscosity and intravascular sludging worsened by associated iron deficiency. Organ damage may result, predominantly noted in cerebrovascular changes from sludging, stroke, and alterations in renal function. Hyperpnea may also occur. Right-sided volume overload and elevated systemic venous pressure may lead to changes in hepatic function. Hyperuricemia may result in gout. Hemoptysis remains a potential threat to life when severe; the occurrence of other clinical bleeding disorders is a matter of debate. Concomitant congenital skeletal abnormalities and restrictive lung disease may worsen hypoxemia. True cardiac ischemic chest pain due to RV ischemia, coronary artery compression by a dilated pulmonary artery, or atherosclerosis may occur with exertion or at rest. Progressive subpulmonary ventricular failure and premature death are the rule in adults with Eisenmenger syndrome, with immediate causes of death including pulmonary ventricular failure, severe hemoptysis from bronchial artery rupture or pulmonary infarction, complications during pregnancy, and cerebral vascular events, including occlusive strokes, systemic paradoxical embolization, and brain abscesses (264,491,492). Death during noncardiac surgery also occurs. Poor functional class is a significant predictor of mortality for Eisenmenger patients, as are serological evidence of low systemic organ perfusion, worsened hypoxemia, and LV systemic dysfunction (493).

9.3. Problems and Pitfalls

Below are the problems and pitfalls in the diagnosis and management of ACHD-related PAH.

- Patients with severe ACHD-related PAH do not have loud murmurs on auscultation because the RV pressure is similar to the LV pressure. In such patients, associated anomalies such as PS should be excluded.
- All potential triggers for PAH, including noncongenital cardiac triggers, should be sought. Therapies for noncongenital triggers should be maximized.
- Diagnosis and therapy hinge on accurate and definitive cardiac catheterization. Additional imaging modalities are often of assistance.
- Oxygen-responsive hypoxemia may occur and should be treated.
- Pregnancy is contraindicated in women with CHD-PAH.

9.4. Recommendations for Evaluation of the Patient With Congenital Heart Disease–Pulmonary Arterial Hypertension

CLASS I

1. **Care of adult patients with CHD-related PAH should be performed in centers that have shared expertise and training in both ACHD and PAH. (*Level of Evidence: C*)**
2. **The evaluation of all ACHD patients with suspected PAH should include noninvasive assessment of cardiovascular anatomy and potential shunting, as detailed below:**
   a. **Pulse oximetry, with and without administration of supplemental oxygen, as appropriate. (*Level of Evidence: C*)**
   b. **Chest x-ray. (*Level of Evidence: C*)**
   c. **ECG. (*Level of Evidence: C*)**
   d. **Diagnostic cardiovascular imaging via TTE, TEE, MRI, or CT as appropriate. (*Level of Evidence: C*)**
   e. **Complete blood count and nuclear lung scintigraphy. (*Level of Evidence: C*)**
3. **If PAH is identified but its causes are not fully recognized, additional testing should include the following:**
   a. **Pulmonary function tests with volumes and diffusion capacity (diffusing capacity of the lung for carbon monoxide). (*Level of Evidence: C*)**
   b. **Pulmonary embolism–protocol CT with parenchymal lung windows. (*Level of Evidence: C*)**
   c. **Additional testing as appropriate to rule out contributing causes of PAH. (*Level of Evidence: C*)**
   d. **Cardiac catheterization at least once, with potential for vasodilator testing or anatomic intervention, at a center with expertise in catheterization, PAH, and management of CHD-PAH. (*Level of Evidence: C*)**

CLASS IIa

1. **It is reasonable to include a 6-minute walk test or similar nonmaximal cardiopulmonary exercise test as part of the functional assessment of patients with CAD-PAH. (*Level of Evidence: C*)**

9.4.1. Dynamic Congenital Heart Disease–Pulmonary Arterial Hypertension

Surgical experience has suggested that the changes that occur with shunt-mediated PAH are reversible, provided the surgery is performed before pulmonary vascular changes are "fixed." Catheterization-based calculations of pulmonary blood flow (Qp) with isolation of all sources of Qp, individualized measurements of resistance in isolated lung segments, and direct measurement of pulmonary venous pressure are typically used to assess PAH reversibility and the likelihood of surgical success. Acute administration of inhaled (nitric oxide) or intravenously administered (prostacyclin) pulmonary vascular agents is frequently used in such investigations to assess for acute reactivity and potential to subsequently (with surgical or pharmacological intervention) mimic achieved lowering of PVR and, when appropriate to anatomy and physiology, similar lowering of pulmonary artery pressures. However, studies have not been performed that firmly establish the pressures, flows, and resistances that define such reactivity. Many centers use a preoperative PVR less than 10 to 14 Wood units and a pulmonary/systemic resistance ratio less than or equal to two thirds as

thresholds associated with better surgical outcomes (494,495), but individual institutions vary with regard to these thresholds, often modifying them according to the specific anatomic lesion and responses to acute vasodilator testing. All additional potential causes of PAH in this population must be excluded, because therapeutic strategies may differ significantly.

An important concept with regard to predicting the outcome of surgery, especially in borderline cases, is that PVR is flow dependent. Thus, it should not be assumed that PVR will necessarily fall in proportion to the reduction in shunt and pulmonary blood flow. High shunt flows can recruit pulmonary vasculature (thereby reducing PVR). With the elimination of shunt, these additionally recruited vascular beds may "de-recruit," no longer accommodating the increased blood flow, and PVR (and hence pulmonary artery pressure) may fall less than would be predicted on the basis of the reduction of blood flow alone.

9.4.2. Eisenmenger Physiology

Diagnosis and evaluation of Eisenmenger physiology require a detailed history to look for all possible PAH triggers and a thorough understanding of current and past anatomy, as well as knowledge of all past surgical and medical interventions. Documentation of the size and direction of intracardiac or intravascular shunts present at the atrial, ventricular, or great arterial level is required, as is a precise documentation of the extent of the severity of pulmonary arteriolar hypertension. A suggested basic evaluation of adults with presumed Eisenmenger physiology includes assessment of anatomy, degree of PAH, ventricular function, and both the presence and magnitude of secondary complications. Evaluation includes finger and toe oximetry, chest x-ray, ECG, pulmonary function tests with volumes and CO_2 diffusion, anatomic lesion definition (by use of noninvasive or invasive modalities, as necessary), pulmonary embolism–protocol CT with "chest windows," complete blood count with indices, ferritin and iron studies, and renal and hepatic function tests, along with 6-minute walk testing (with or without oximetry or cardiopulmonary testing). Other tests may be performed as indicated if the diagnosis is less certain: hepatitis B and C panels; cryoglobulins; human immunodeficiency virus serologies; procoagulant evaluation; and rheumatologic serologies (including scleroderma, mixed connective tissue disorder, and systemic lupus erythematosus). A complete cardiac catheterization, with potential for vasodilator testing or anatomic interventions, should be performed, but only at a center with expertise in the diagnosis and management of ACHD and adult patients with PAH. Open lung biopsy presently has a very limited role in patient diagnosis or management.

9.5. Management Strategies

9.5.1. Recommendations for Medical Therapy of Eisenmenger Physiology

CLASS I

1. **It is recommended that patients with Eisenmenger syndrome avoid the following activities or exposures, which carry increased risks:**
   a. **Pregnancy. (*Level of Evidence: B*)**
   b. **Dehydration. (*Level of Evidence: C*)**
   c. **Moderate and severe strenuous exercise, particularly isometric exercise. (*Level of Evidence: C*)**
   d. **Acute exposure to excessive heat (eg, hot tub or sauna). (*Level of Evidence: C*)**
   e. **Chronic high-altitude exposure, because this causes further reduction in oxygen saturation and increased risk of altitude-related cardiopulmonary complications (particularly at an elevation greater than 5000 feet above sea level). (*Level of Evidence: C*)**
   f. **Iron deficiency. (*Level of Evidence: B*)**
2. **Patients with Eisenmenger syndrome should seek prompt therapy for arrhythmias and infections. (*Level of Evidence: C*)**
3. **Patients with Eisenmenger syndrome should have hemoglobin, platelet count, iron stores, creatinine, and uric acid assessed at least yearly. (*Level of Evidence: C*)**
4. **Patients with Eisenmenger syndrome should have assessment of digital oximetry, both with and without supplemental oxygen therapy, at least yearly. The presence of oxygen-responsive hypoxemia should be investigated further. (*Level of Evidence: C*)**
5. **Exclusion of air bubbles in intravenous tubing is recommended as essential during treatment of adults with Eisenmenger syndrome. (*Level of Evidence: C*)**
6. **Patients with Eisenmenger syndrome should undergo noncardiac surgery and cardiac catheterization only in centers with expertise in the care of such patients. In emergent or urgent situations in which transportation is not feasible, consultation with designated caregivers in centers with expertise in the care of patients with Eisenmenger syndrome should be performed and sustained throughout care. (*Level of Evidence: C*)**

CLASS IIa

1. **All medications given to patients with Eisenmenger physiology should undergo rigorous review for the potential to change systemic blood pressure, loading conditions, intravascular shunting, and renal or hepatic flow or function. (*Level of Evidence: C*)**
2. **Pulmonary vasodilator therapy can be beneficial for patients with Eisenmenger physiology because of the potential for improved quality of life. (*Level of Evidence: C*)**

An emphasis on patient education and avoidance of destabilizing situations and volume shifts that result in alteration of catecholamines, extreme fatigue, high-altitude exposure, contact with cigarette smoke, changes in renal or hepatic function, or use of medications that may modulate flow to or function of these organs is advocated. Avoidance of pregnancy and iron deficiency and prompt therapy for arrhythmia or infection are recommended. A concept of team planning for all procedures is mandated because of the potential for morbid and mortal outcomes of even the simplest of interventions for any ailment. The optimal type and mode of anesthetic administration should be individualized by experts in the care of persons with Eisenmenger physiology. Risk of right-to-left embolization warrants avoidance of bubbles, and consideration of the use of air filters on all venous catheters still tends to be advocated, although controversy exists regarding the relative benefit obtained compared with meticulous guarding of all intravenous administration systems.

Erythrocytosis tends to remain stable in cyanotic patients, and alterations in serum hemoglobin tend to be indicative of intercurrent issues that require their own correction (refer to

Section 7.6.5, Cyanosis). Therapeutic phlebotomy or erythropheresis has a very limited role in patient management and should only be performed if the hemoglobin is more than 20 g per dL and the hematocrit is greater than 65% with associated symptoms of hyperviscosity and no evidence of dehydration. Iron deficiency anemia should be avoided, given the suggestion that iron-deficient red blood cells with less oxygen-carrying capacity and less potential for deformation may lead to increased incidence of strokes and vascular complication (184). Achievement of replete iron stores, combined with optimal serum hemoglobin and blood viscosity, is the optimal approach (496,497).

Therapies for adults with CHD-PAH have been limited and have included oxygen, warfarin, diuretics, calcium channel blockers, long-term continuous intravenous epoprostenol, oral prostacyclin analogues, oral endothelin antagonists, oral phosphodiesterase inhibition, and lung or lung/heart transplantation. The benefit of supplemental oxygen administration is a matter of debate given the conflict between recognized concomitant oxygen-responsive and -unresponsive components to hypoxemia in many patients and the lack of sufficient trial data to assess benefit (498,499). The use of oxygen therapy may help if there is a component of oxygen-responsive vasoconstriction. Despite few data, calcium channel blockers have shown limited results or have worsened well-being.

Transplantation has offered a limited survival benefit for this patient population, given the unpredictability of transplant-free survival and significantly higher perioperative mortality in this cohort of patients, although individual outcomes may warrant individual considerations (500). Newer theoretical procedures such as pulmonary artery banding have not been studied adequately. Symptomatic adults with Eisenmenger physiology should be counseled about the results of randomized, controlled trials of vasomodulator therapies for PAH, with particular emphasis on those trials performed specifically in adults with Eisenmenger physiology.

Anticoagulation with warfarin is widely used in patients with PAH on the basis of observational studies, in the absence of randomized, controlled trials supporting benefit or evaluating risk. In adults with Eisenmenger physiology, recognition of in vivo pulmonary thrombus (350), contrasted with reports of in vitro abnormalities of coagulation in persons with cyanosis (501), has led to debate over the potential benefit of oral anticoagulant therapy, particularly with the concomitant bleeding diathesis inherent in the condition. In patients with active or chronic hemoptysis, anticoagulation is contraindicated.

The theoretical possibility of worsening of right-to-left shunting raises questions about the safety of using pulmonary artery modulating therapies that also have systemic vasodilator potential. Nevertheless, some of these agents (intravenous prostacyclin and oral sildenafil) have yielded improvements in hemodynamics, exercise tolerance, and/or systemic arterial oxygen saturation in limited case studies (501–507). The potential for significant adverse reaction due to these agents has been recognized.

Randomized, controlled trials showing a benefit of many of these agents for patients with PAH have included small numbers of patients with Eisenmenger physiology; however, the utility of these trials in guiding therapy for patients with Eisenmenger physiology is limited, given that the trials were not designed to test hypotheses specifically in such patients and were not randomized to therapy within an Eisenmenger subgroup (505–509). Results of the first randomized, controlled trial of medical therapy in adults with Eisenmenger syndrome due to predominantly either ASD or VSD, with oral bosentan compared with placebo (BREATHE-5, the Bosentan Randomized trial of Endothelin Antagonist THErapy-5), documented therapeutic safety and improvement in symptomatic measures, 6-minute walk distance, and hemodynamics after short-term (4 months) use of bosentan (510). The use of these agents should be restricted to centers with demonstrated expertise in CHD-PAH.

9.6. Key Issues to Evaluate and Follow-Up

9.6.1. Recommendations for Reproduction

CLASS I

1. **Women with severe CHD-PAH, especially those with Eisenmenger physiology, and their partners should be counseled about the absolute avoidance of pregnancy in view of the high risk of maternal death, and they should be educated regarding safe and appropriate methods of contraception. (*Level of Evidence: B*)**
2. **Women with CHD-PAH who become pregnant should:**
   a. **Receive individualized counseling from cardiovascular and obstetric caregivers collaborating in care and with expertise in management of CHD-PAH. (*Level of Evidence: C*)**
   b. **Undergo the earliest possible pregnancy termination after such counseling. (*Level of Evidence: C*)**
3. **Surgical sterilization carries some operative risk for women with CHD-PAH but is a safer option than pregnancy. In view of advances in minimally invasive techniques, the risks and benefits of sterilization modalities should be discussed with an obstetrician experienced in management of high-risk patients, as well as with a cardiac anesthesiologist. (*Level of Evidence: C*)**

CLASS IIb

1. **Pregnancy termination in the last 2 trimesters of pregnancy poses a high risk to the mother. It may be reasonable, however, after the risks of termination are balanced against the risks of continuation of the pregnancy. (*Level of Evidence: C*)**

CLASS III

1. **Pregnancy in women with CHD-PAH, especially those with Eisenmenger physiology, is not recommended and should be absolutely avoided in view of the high risk of maternal mortality. (*Level of Evidence: B*)**
2. **The use of single-barrier contraception alone in women with CHD-PAH is not recommended owing to the frequency of failure. (*Level of Evidence: C*)**
3. **Estrogen-containing contraceptives should be avoided. (*Level of Evidence: C*)**

9.6.2. Pregnancy

Pregnancy carries particular risk for individuals with CHD-PAH, especially those with Eisenmenger physiology, with

mostly older case series suggesting maternal mortality in the latter group of up to 50% and similarly high levels of fetal loss. Even after a successful pregnancy, maternal mortality may be particularly increased in the first several days after delivery (511). Termination of pregnancy, particularly in its mid and later phases, with its concomitant volume and hormonal fluctuations also carries a high maternal risk. Termination in the first trimester is the safer option. Recent case series have reported individual ability of the adult with Eisenmenger physiology to survive pregnancy with concomitant use of modern vasomodulatory agents. It remains unclear whether the potential for pregnancy survival is any different in persons with Eisenmenger syndrome than in adults with PAH without intravascular shunting, and because of the lack of predictability of outcome, pregnancy remains absolutely contraindicated for these patients. Counseled contraception is strongly advised, although the particular method of such is a matter of debate. Maternal sterilization carries a defined operative risk of mortality, and endoscopic sterilization may be the safer option. Hormonal therapies increase the preexisting potential for thrombosis, although progesterone-only preparations may be considered. Barrier methods have an increased rate of failure, and intrauterine device implantation carries anecdotally increased infection risk, although the highest risk is for local infection in multipartner couples. There is no consensus on comparative contraceptive risks; therefore, the patient should discuss options with a high-risk obstetrician (maternal fetal medicine specialist).

9.6.3. Other Interventions

There are limited case data on surgical or transcatheter attempts to limit pulmonary blood flow so as to potentially remodel the pulmonary vascular bed and alter PVR (509).

9.6.4. Recommendations for Follow-Up

CLASS I

1. **Patients with CHD-related PAH should:**
   a. **Have coordinated care under the supervision of a trained CHD and PAH provider and be seen by such individuals at least yearly. (*Level of Evidence: C*)**
   b. **Have yearly comprehensive evaluation of functional capacity and assessment of secondary complications. (*Level of Evidence: C*)**
   c. **Discuss all medication changes or planned interventions with their CHD-related PAH caregiver. (*Level of Evidence: C*)**

CLASS III

1. **Endocardial pacing is not recommended in patients with CHD-PAH with persistent intravascular shunting, and alternative access for pacing leads should be sought (the risks should be individualized). (512) (*Level of Evidence: B*)**

9.6.5. Endocarditis Prophylaxis

Refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information.

10. Tetralogy of Fallot

10.1 Definition and Associated Lesions

Tetralogy of Fallot has 4 components: subpulmonary infundibular stenosis, a VSD, an aorta that overrides the VSD by less than 50% of its diameter, and RV hypertrophy. There can be varying levels of severity, and a morphological spectrum exists. The most extreme form is pulmonary atresia with VSD, which is not discussed here. The single and large VSD is usually in the subaortic position. The pulmonary valve is often small and stenotic. Pulmonary artery anomalies are frequent and include hypoplasia and stenosis. Pulmonary artery hypoplasia may involve the pulmonary trunk or the branch pulmonary arteries. Pulmonary artery stenosis at any of these levels is common. Occasionally, the pulmonary artery is absent, most often on the left side. Associated anomalies can include a secundum ASD, AVSD (usually in a patient with Down syndrome), and a right aortic arch in approximately 25% of cases. Coronary artery anomalies also occur, most commonly with a left anterior descending coronary artery arising from the right coronary artery and crossing the RVOT (approximately 3% of cases).

10.2. Clinical Course (Unrepaired)

10.2.1. Presentation as an Unoperated Patient

Presentation as an unoperated patient is now rare in countries with access to modern cardiac surgery, but it can be seen in immigrants living in the United States and in patients who live in countries without access to surgical repair. An occasional patient is seen with relatively mild pulmonary obstruction and mild cyanosis (the so-called pink tetralogy), in which case the diagnosis may not be made until adult life. It is usually mistaken for a small VSD because of the loud precordial murmur. Other patients who have not had previous access to health care and who have severe RV outflow obstruction but abundant aorticopulmonary collaterals may present late with cyanosis and loud continuous murmurs over the thorax. TTE and cardiac catheterization may confirm the diagnosis. The course and anatomy of the epicardial coronary arteries should be defined before definitive repair.

10.2.2. Postsurgical Presentation

Almost all patients with repairable forms of tetralogy of Fallot in the United States will have had reparative surgery. They are usually asymptomatic. Exercise limitation or atrial and/or ventricular arrhythmias imply hemodynamic difficulties.

10.3. Clinical Features and Evaluation

10.3.1. Clinical Examination

The typical postrepair patient has a soft ejection systolic murmur from the RVOT. The presence of a low-pitched, delayed diastolic murmur in the pulmonary area is consistent with pulmonary regurgitation. Such patients usually have an absent P_2 component of the second sound. The patient may have a pansystolic murmur of a VSD patch leak. A diastolic murmur of AR may also be heard. The occasional adult patient may present having had a palliative shunt only. Such patients usually have cyanosis and clubbing. If the shunt is patent, a continuous murmur may be heard. In the

presence of a prior classic Blalock-Taussig shunt, the brachial and radial pulses may be diminished or absent on that side.

10.3.2. Electrocardiogram

In patients with transventricular repairs (the norm until the 1990s), complete right bundle-branch block is almost always present, in which case QRS duration may reflect the degree of RV dilation. A QRS duration of 180 ms or more has been identified as a risk factor for sustained VT and sudden cardiac death (167). The presence of atrial flutter or fibrillation or of sustained VT reflects severe hemodynamic difficulties (513,514).

10.3.3. Chest X-Ray

In patients with a good hemodynamic result, the heart size is usually normal. Cardiomegaly usually reflects important pulmonary regurgitation and/or TR. The aortic arch is right-sided in 25% of cases.

10.3.4. Initial Surgical Repair

Complete repair is considered 1) in palliated patients without irreversible PAH or unfavorable pulmonary artery anatomy and 2) as a primary operation, usually performed in the first year of life. An adult who has undergone palliation earlier in life can be considered for surgery for complete repair after thorough evaluation indicates favorable anatomy and hemodynamics.

Complete repair consists of VSD closure and relief of RVOT obstruction. Relief of RVOT obstruction may include simple resection of infundibular stenosis (muscle), but if the pulmonary annulus is small, more extensive surgery may be necessary. This may include RV outflow patch augmentation or placement of a transannular patch that disrupts the integrity of the pulmonary valve. Occasionally, an extracardiac conduit must be placed from the right ventricle to the pulmonary artery when an anomalous coronary artery crosses the RVOT. If the pulmonary valve itself is abnormal, a pulmonary valvotomy or pulmonary valve resection may be necessary. Effort should be made to preserve the pulmonary valve during the primary operation when performed in infancy. A PFO or small ASD is usually closed. When complete repair is performed in adulthood, pulmonary valve replacement may be required if the native pulmonary valve integrity is disrupted (Table 14).

Key postoperative issues are summarized below:

- Residual pulmonary regurgitation
- RV dilation and dysfunction from pulmonary regurgitation, possibly with associated TR
- Residual RVOT obstruction
- Branch pulmonary artery stenosis or hypoplasia
- Sustained VT
- Sudden cardiac death
- AV block, atrial flutter, and/or atrial fibrillation
- Progressive AR
- Syndromal associations.

The most common problem encountered in the adult patient after repair is that of pulmonary regurgitation. This is frequently missed on clinical examination because the murmur is short and quiet and the pulmonary regurgitation is often overlooked on echocardiography. Patients who present with arrhythmias or cardiomegaly should undergo a thorough evaluation to rule out underlying hemodynamic abnormalities. AR may also occur, often accompanied by aortic root dilatation.

Table 14. Surgical Procedures for Rerepair of Tetralogy of Fallot in Adults

Pulmonary valve replacement
• Heterograft (porcine or pericardial) or homograft
• Mechanical PVR in patients who require warfarin anticoagulation for other reasons. This procedure has been associated with late malfunction from pannus formation.
• Patch augmentation of the pulmonary annulus for proper prosthetic valve sizing
Subvalvular obstruction or pulmonary artery stenosis
• Resection of subvalvular obstruction and/or patch augmentation of the RVOT, pulmonary annulus, main or branch pulmonary arteries
• Usually occurs in combination with PVR
Residual/recurrent VSD closure
• Direct suture
• Patch revision
AVR (tissue or mechanical) for aortic regurgitation
Replacement of ascending aorta for dilatation
• Tube graft
• Bentall procedure (composite valved conduit with coronary reimplantation)
Aneurysm or pseudoaneurysm formation of RVOT
• Resection and patch replacement
Atrial arrhythmias
• Maze procedure or 1 of its modifications
Ventricular arrhythmias (ventricular tachycardia, ventricular fibrillation)
• Preoperative EP testing and ablation in the catheterization laboratory
• If unsuccessful, intraoperative mapping and ablation are performed
• Focus is most often in the RVOT between the VSD patch and the pulmonary annulus
• Postoperative placement of an ICD for patients at high risk of sudden death
Tricuspid valve repair for significant tricuspid regurgitation
Tricuspid valve replacement for a markedly abnormal tricuspid valve
Closure of residual PFO or ASD, especially if there is cyanosis, history of paradoxical embolism, or anticipated need for a permanent pacemaker or ICD

PVR indicates pulmonary vascular resistance; RVOT, right ventricular outflow tract; VSD, ventricular septal defect; AVR, aortic valve replacement; EP, electrophysiology; ICD, implantable cardioverter defibrillator; PFO, patent foramen ovale; and ASD, atrial septal defect.

10.4. Recommendations for Evaluation and Follow-Up of the Repaired Patient

CLASS I

1. **Patients with repaired tetralogy of Fallot should have at least annual follow-up with a cardiologist who has expertise in ACHD. (*Level of Evidence: C*)**
2. **Patients with tetralogy of Fallot should have echocardiographic examinations and/or MRIs performed by staff with expertise in ACHD. (*Level of Evidence: C*)**

3. Screening for heritable causes of their condition (eg, 22q11 deletion) should be offered to all patients with tetralogy of Fallot. (*Level of Evidence: C*)
4. Before pregnancy or if a genetic syndrome is identified, consultation with a geneticist should be arranged for patients with tetralogy of Fallot. (*Level of Evidence: B*)
5. Patients with unrepaired or palliated forms of tetralogy should have a formal evaluation at an ACHD center regarding suitability for repair. (*Level of Evidence: B*)

All patients should have regular follow-up with a cardiologist who has expertise in ACHD (3,4,10,43,82,515,516). The frequency, although typically annual, may be determined by the extent and degree of residual abnormalities. Appropriate imaging (2-dimensional echocardiography annually in most cases and/or MRI every 2 to 3 years) should be undertaken by staff trained in imaging of complex congenital heart defects. An ECG should be performed annually to assess cardiac rhythm and to evaluate QRS duration. Periodic cardiopulmonary testing may be helpful to facilitate serial follow-up of exercise capacity and to evaluate the potential for exercise-induced arrhythmias. Other testing should be arranged in response to clinical problems, particularly a Holter monitor if there is concern about arrhythmias.

10.4.1. Recommendation for Imaging

CLASS I

1. Comprehensive echocardiographic imaging should be performed in a regional ACHD center to evaluate the anatomy and hemodynamics in patients with repaired tetralogy of Fallot. (*Level of Evidence: B*)

Echocardiography is usually very helpful in assessing a patient after repair of tetralogy. The presence and severity of residual RVOT obstruction and pulmonary regurgitation can usually be assessed along with the presence or absence of TR. The tricuspid regurgitant velocity facilitates measurement of the RV pressure. A residual VSD may be seen. RV volume and wall motion are not reliably quantified by standard techniques, although size and function can be determined qualitatively. Doppler measurement of the RV myocardial performance index may be a useful adjunct to serial assessment of RV systolic function. Atrial size can be assessed. Aortic root dilation and AR should be sought and evaluated at regular intervals.

MRI is now seen as the reference standard (517,518) for assessment of RV volume and systolic function. It can be helpful in assessing the severity of pulmonary regurgitation and in evaluating important associated pathology, especially involving the pulmonary arteries and the ascending aorta. Left-sided heart disease can also be evaluated. Recently, CT scanning has become available (519–521) to make similar measurements of RV volume and systolic function and is potentially helpful in patients who cannot have an MRI, although because of the higher radiation exposure, it is not suitable for serial measurements.

10.5. Recommendations for Diagnostic and Interventional Catheterization for Adults With Tetralogy of Fallot

CLASS I

1. Catheterization of adults with tetralogy of Fallot should be performed in regional centers with expertise in ACHD. (*Level of Evidence: C*)
2. Coronary artery delineation should be performed before any intervention for the RVOT. (*Level of Evidence: C*)

CLASS IIb

1. In adults with repaired tetralogy of Fallot, catheterization may be considered to better define potentially treatable causes of otherwise unexplained LV or RV dysfunction, fluid retention, chest pain, or cyanosis. In these circumstances, transcatheter interventions may include:
   a. Elimination of residual shunts or aortopulmonary collateral vessels. (*Level of Evidence: C*)
   b. Dilation (with or without stent implantation) of RVOT obstruction. (*Level of Evidence: B*)
   c. Elimination of additional muscular or patch margin VSD. (*Level of Evidence: C*)
   d. Elimination of residual ASD. (*Level of Evidence: B*)

For the unusual case of a patient with tetralogy of Fallot who has undergone palliation with a surgical shunt, catheterization should be performed to assess the potential for repair. The presence or absence of additional muscular VSDs may be determined, as well as the course and anatomy of the epicardial coronary arteries. The pulmonary architecture and vascular pressure and resistance should be delineated, because pulmonary artery distortion and PAH are frequent sequelae of palliative surgical shunts. Potential catheter interventions include elimination of collateral vessels or systemic–pulmonary artery shunts, dilation/stent implantation of obstructed pulmonary arteries, and, more recently, the possibility of percutaneous pulmonary valve implantation. Heart catheterization is not used routinely in the assessment of patients who have undergone repair, except when surgery or other therapy is being considered or for the evaluation of the pulmonary and coronary arteries.

10.5.1. Branch Pulmonary Artery Angioplasty

Balloon angioplasty of a branch pulmonary artery results in intimal and medial dissection and subsequent inflammatory repair and increase in vessel size. Dilation may be considered when RV pressure is more than 50% of the systemic level or at lower pressure when there is RV dysfunction. Balloon pulmonary artery angioplasty may also be considered when there is unbalanced pulmonary blood flow greater than 75%, 25%, or otherwise unexplained dyspnea with severe vascular stenosis (522,523). Pulmonary artery balloon angioplasty may be an effective way to reduce obstruction to pulmonary blood flow, thereby increasing pulmonary vascular capacitance and decreasing PVR (524). Balloon angioplasty is usually effective for intermediate-branch pulmonary artery stenoses/occlusions, although it may require coimplantation of large stents (up to 24 to 26 mm diameter in width, up to 5.8 cm in length) in more proximal main and early branch pulmonary arteries or right ventricle–to–pulmonary artery conduits. Intravascular stents are

of potential benefit as well in the presence of intimal flaps, vessel kinks, and stenoses, especially in the early perioperative period. Postdeployment antiinflammatory or antiproliferative/anticoagulant strategies remain undefined. Stent redilation has been shown to be effective in selected patients as late as 10 years after implantation (525). The applicability of these techniques has recently been extended to adults with very distal segmental pulmonary artery stenoses and appears promising (427,526). The transcatheter approach to the management of residual muscular or patch margin VSDs (indications typically include a Qp/Qs greater than 1.5 to 2.0, or less in the setting of PAH, left atrial hypertension, or LV failure) remains an effective alternative to reoperative surgical closure (527,528).

10.5.2. Exercise Testing

Exercise testing may be used to assess functional capacity objectively and to evaluate possible exertional arrhythmias. Serial evaluations may be helpful (55,529).

10.5.3. Diagnostic Catheterization

Catheter assessments and interventions for adults with previously repaired tetralogy of Fallot are indicated for the following when adequate data cannot be obtained noninvasively:

- Assessment of hemodynamics
- Assessment of pulmonary blood flow and resistance
- Assessment of the nature of RV outflow or pulmonary artery obstruction
- Delineation of coronary artery origin and course before any interventional procedure
- Assessment of ventricular function and presence of residual septal defects, as well as assessment of the degree of mitral regurgitation or AR. The potential for placement of transcatheter implants to reduce or eliminate residual VSDs should be discussed in advance with the patient and medical-surgical team
- Assessment of the significance of flow across a PFO or ASD and its potential elimination
- Performance of coronary angiography, with potential to eliminate symptomatic obstructive lesions
- Assessment of pulmonary regurgitation and right-sided heart failure.

10.6. Problems and Pitfalls in the Patient With Prior Repair

The following problems occur in patients after repair of tetralogy of Fallot:

- Cardiomegaly on chest x-ray should prompt the search for a residual hemodynamic lesion (commonly pulmonary regurgitation).
- The development of arrhythmias (atrial or ventricular) should prompt the search for an underlying hemodynamic abnormality (commonly pulmonary regurgitation).
- Diagnostic confusion may occur in the context of double-outlet right ventricle, in which the aorta overrides the right ventricle by more than 50%. In such cases, the VSD patch is more extensive and predisposes to the presence of postoperative subaortic obstruction, which should be carefully excluded.
- Hypoxemia in postoperative patients should prompt a search for a PFO or ASD with a right-to-left shunt.
- The presence of RV enlargement or dysfunction and the presence of important TR should prompt the search for a residual hemodynamic lesion (commonly pulmonary regurgitation).

Some postoperative patients may have LV dysfunction. This may relate to prolonged cardiopulmonary bypass, poor myocardial protection from an early surgical era, or trauma to a coronary artery at the time of repair, or it may be secondary to severe RV dysfunction.

10.7. Management Strategy for the Patient With Prior Repair

10.7.1. Medical Therapy

Most patients need no regular medication in the absence of significant residual hemodynamic abnormality. Heart failure medications may be necessary in the setting of RV and LV dysfunction.

10.8. Recommendations for Surgery for Adults With Previous Repair of Tetralogy of Fallot

CLASS I

1. **Surgeons with training and expertise in CHD should perform operations in adults with previous repair of tetralogy of Fallot. (*Level of Evidence: C*)**
2. **Pulmonary valve replacement is indicated for severe pulmonary regurgitation and symptoms or decreased exercise tolerance. (*Level of Evidence: B*)**
3. **Coronary artery anatomy, specifically the possibility of an anomalous anterior descending coronary artery across the RVOT, should be ascertained before operative intervention. (*Level of Evidence: C*)**

CLASS IIa

1. **Pulmonary valve replacement is reasonable in adults with previous tetralogy of Fallot, severe pulmonary regurgitation, and any of the following:**
   a. **Moderate to severe RV dysfunction. (*Level of Evidence: B*)**
   b. **Moderate to severe RV enlargement. (*Level of Evidence: B*)**
   c. **Development of symptomatic or sustained atrial and/or ventricular arrhythmias. (*Level of Evidence: C*)**
   d. **Moderate to severe TR. (*Level of Evidence: C*)**
2. **Collaboration between ACHD surgeons and ACHD interventional cardiologists, which may include preoperative stenting, intraoperative stenting, or intraoperative patch angioplasty, is reasonable to determine the most feasible treatment for pulmonary artery stenosis. (*Level of Evidence: C*)**
3. **Surgery is reasonable in adults with prior repair of tetralogy of Fallot and residual RVOT obstruction (valvular or subvalvular) and any of the following indications:**
   a. **Residual RVOT obstruction (valvular or subvalvular) with peak instantaneous echocardiography gradient greater than 50 mm Hg. (*Level of Evidence: C*)**
   b. **Residual RVOT obstruction (valvular or subvalvular) with RV/LV pressure ratio greater than 0.7. (*Level of Evidence: C*)**

Table 15. Estimates of Sudden Death After Tetralogy of Fallot Surgery

First Author of Study	Reference	Year of Study	No. of Patients	Incidence of Sudden Death
Murphy	530	1993	163	6% of cases followed up 30 years
Nollert	162	1997	490	3% of cases followed up 25 years
Silka	346	1998	N/A	Approximately 2 deaths per 1000 patient-years
Norgaard	531	1999	125	5.6% of cases followed up 25 years
Gatzoulis	166	2000	793	6% of cases followed up 21 years

N/A indicates not available.

c. Residual RVOT obstruction (valvular or subvalvular) with progressive and/or severe dilatation of the right ventricle with dysfunction. (*Level of Evidence: C*)

d. Residual VSD with a left-to-right shunt greater than 1.5:1. (*Level of Evidence: B*)

e. Severe AR with associated symptoms or more than mild LV dysfunction. (*Level of Evidence: C*)

f. A combination of multiple residual lesions (eg, VSD and RVOT obstruction) leading to RV enlargement or reduced RV function. (*Level of Evidence: C*)

Late survival after tetralogy repair is excellent; 35-year survival is approximately 85%. The need for reintervention, usually for pulmonary valve insertion, increases after the second decade of life. Surgical intervention is indicated for symptomatic patients with severe pulmonary regurgitation or asymptomatic patients with severe PS or pulmonary regurgitation in association with signs of progressive or severe RV enlargement or dysfunction. Patients with RV–to–pulmonary artery conduit repairs often require further intervention for conduit stenosis or regurgitation. Any intervention that involves the RVOT requires careful preoperative assessment of the coronary anatomy to avoid interruption of an important coronary vessel. Some patients experience increasing AR, which requires surgical intervention.

10.8.1. Recommendations for Interventional Catheterization

CLASS I

1. Interventional catheterization in an ACHD center is indicated for patients with previously repaired tetralogy of Fallot with the following indications:

a. To eliminate residual native or palliative systemic–pulmonary artery shunts. (*Level of Evidence: B*)

b. To manage coronary artery disease. (*Level of Evidence: B*)

CLASS IIa

1. Interventional catheterization in an ACHD center is reasonable in patients with repaired tetralogy of Fallot to eliminate a residual ASD or VSD with a left-to-right shunt greater than 1.5:1 if it is in an appropriate anatomic location. (*Level of Evidence: C*)

Interventional catheterization in previously repaired tetralogy of Fallot should be planned carefully with the medical and surgical team in an ACHD center. Although there is experience in the use of catheter devices to close residual shunts, experience with the use of percutaneous stent-valve implants in the RV outflow for patients with pulmonary regurgitation and right-sided heart failure is recent, and efficacy/safety remains undefined, but this technique appears promising.

10.9. Key Issues to Evaluate and Follow-Up

10.9.1. Recommendations for Arrhythmias: Pacemaker/Electrophysiology Testing

CLASS I

1. Annual surveillance with history, ECG, assessment of RV function, and periodic exercise testing is recommended for patients with pacemakers/automatic implantable cardioverter defibrillators. (*Level of Evidence: C*)

CLASS IIa

1. Periodic Holter monitoring can be beneficial as part of routine follow-up. The frequency should be individualized depending on the hemodynamics and clinical suspicion of arrhythmia. (*Level of Evidence: C*)

CLASS IIb

1. Electrophysiology testing in an ACHD center may be reasonable to define suspected arrhythmias in adults with tetralogy of Fallot. (*Level of Evidence: C*)

Despite overall excellent hemodynamic outcomes after surgery for tetralogy of Fallot, there remains a concerning incidence of unexpected sudden death during long-term follow-up (Table 15). VT appears to be the mechanism responsible for most of these events, although rapidly conducted IART (atrial flutter) or AV block may be responsible in some cases. The incidence of sudden death for the adult tetralogy population can be estimated from several large series to be on the order of 2.5% per decade of follow-up (162,166,346,530,531). Although this incidence is lower than the risk of sudden cardiac death in other forms of adult heart disease (eg, ischemic myopathy or hypertrophic myopathy), it is nonetheless a devastating outcome that has been the topic of intense clinical investigation for more than 30 years (Table 16).

Numerous studies have attempted to define the mechanism and risk factors for the development of sudden arrhythmic death in this group. To date, no perfect risk-stratification scheme has emerged, although several isolated variables have been identified that correlate modestly well with malignant arrhythmias. As shown in Table 16, the earliest of these is related to compromised AV conduction, with the hypothesis that trauma to AV conduction tissues at the time of surgery (enough to cause permanent bifascicular block) could lead to late sudden death, presumably due to abrupt worsening of conduction with asystole (532). By the 1980s, however, the

Table 16. Potential Risk Factors for Sudden Death After Tetralogy of Fallot Surgery

First Author of Study	Reference	Year	AV Block	Holter	EPS	RV Function	Shunt	Age Surg	ECG
Wolff	532	1972	Yes	...	...	...	...	...	...
Gillette	533	1977	...	Yes	...	...	...	...	...
Deanfield	534	1983	No	Yes	...	...	...	...	...
Horowitz	535	1980	...	...	Yes	...	...	...	...
Kugler	536	1983	...	...	Yes	...	...	...	...
Dunnigan	537	1984	...	...	Yes	...	...	...	...
Garson	538	1985	...	Yes	...	Yes	Yes	Yes	...
Walsh	140	1988	...	...	...	...	...	Yes	...
Chandar	165	1990	...	Yes	No	Yes	...	Yes	...
Zimmermann	539	1991	...	Yes	...	...	...	...	...
Downar	540	1992	...	...	...	Yes	...	...	...
Murphy	530	1993	...	...	...	Yes	...	Yes	...
Cullen	541	1994	...	No	...	...	...	...	...
Jonsson	542	1995	...	Yes	Yes	...	...	Yes	...
Gatzoulis	167	1995	...	...	...	Yes	Yes	Yes	Yes
Balaji	543	1997	...	...	...	...	...	...	Yes
Nollert	162	1997	...	...	...	Yes	...	Yes	...
Berul	544	1997	...	...	...	...	...	...	Yes
Daliento	223	1999	...	...	...	...	Yes	...	Yes
Gatzoulis	166	2000	...	...	...	Yes	Yes	Yes	Yes
Therrien	170	2001	...	...	...	Yes	...	...	Yes
Hokanson	545	2001	Yes	...	...	...	...	...	...
Hamada	546	2002	...	...	...	...	...	Yes	...
Ghai	547	2002	...	Yes	...	Yes	...	...	Yes
Dore	548	2004	...	...	...	...	...	...	No
Khairy	169	2004	...	Yes	Yes	...	Yes	Yes	...
Russo	549	2005	...	...	...	...	...	...	No

Yes indicates that the study supports the variable as being predictive of malignant arrhythmias. No indicates that the study does not support the variable as being predictive of malignant arrhythmias.

An ellipsis indicates that the category of data is not applicable.

AV Block indicates atrioventricular block; Holter, high-grade ventricular ectopy on Holter monitoring; EPS, positive ventricular stimulation at electrophysiology study; RV function, right ventricular function (including pulmonary regurgitation or residual pulmonary outflow obstruction); Shunt, history of prior palliative shunt surgery; Age Surg, older age at time of definitive surgery; and ECG, electrocardiographic findings (QRS duration, JT dispersion, etc).

emphasis shifted away from AV block toward VT as the more common mechanism for sudden death in tetralogy patients (533–537). Multiple clinical and laboratory variables have since been linked to an elevated likelihood of VT, although the predictive accuracy for all these items remains imperfect. The general picture that emerges for the high-risk tetralogy patient involves some combination of 1) long-standing palliative shunts, 2) older age at the time of definitive surgery, 3) abnormal RV hemodynamics (due to pulmonary regurgitation and/or residual outflow obstruction), 4) high-grade ectopy on Holter monitor, and 5) inducible VT at electrophysiological study. (140,165,167,169,170,223,538–549) In addition, it has recently become apparent that reasonable correlation exists between VT and certain ECG findings, particularly QRS duration greater than 180 ms (167,170). This is not surprising considering that the most dramatic degrees of QRS prolongation tend to be seen among tetralogy patients with highly dysfunctional and dilated right ventricles (so-called mechanoelectric interaction). The QRS width on ECG can thus be viewed as a crude proxy for size and function of the right ventricle and can be tracked easily in any adult tetralogy patient who is not pacemaker dependent.

The proper risk-stratification approach to an asymptomatic adult with repaired tetralogy is a matter of debate. Most clinicians rely on a yearly evaluation with careful history, physical examination, and ECG, supplemented every few years with Holter monitoring or exercise testing to screen for high-grade ventricular ectopy, as well as periodic echocardiograms or MRIs to monitor the functional status of the right ventricle. Should nonsustained VT be detected on surveillance monitoring in an asymptomatic patient, or should RV function appear to be deteriorating, opinions still vary widely as to the appropriate response. Some would recommend electrophysiology study to refine the arrhythmia risk; some would advise surgery for pulmonary valve replacement if regurgitation exists; some would prescribe antiarrhythmic drugs; some would implant a primary prevention defibrillator; and some refrain from

treatment as long as the patient remains free of symptoms. In the absence of firm outcome data, no single approach can be dismissed or advocated, so that therapy continues to be individualized for asymptomatic patients depending largely on institutional experience and philosophy.

Worrisome symptoms (ie, palpitations, dizziness, or an episode of syncope) should obviously heighten the index of suspicion for serious arrhythmias in tetralogy patients and trigger a prompt evaluation, including hemodynamic catheterization and electrophysiology study. At most centers, treatment is usually tailored according to data obtained from these invasive studies (169). Programmed ventricular stimulation during electrophysiology study provides reasonably good predictive information regarding the risk of future clinical VT events and all-cause mortality. In addition, if stable monomorphic VT can be induced and sustained sufficiently long to permit mapping, catheter ablation of the VT circuit might be considered. An electrophysiology study could also uncover IART (atrial flutter) as a contributing or confounding factor for a patient's symptoms, which might be addressed with catheter ablation at the same setting. Repairable hemodynamic issues may also be identified by echocardiography or cardiac catheterization that could possibly shift therapy toward a surgical approach, such as closure of a residual septal defect or relief of valve regurgitation, combined with intraoperative VT mapping and ablation.

Serious symptoms in adult patients with tetralogy of Fallot (ie, documented sustained VT or cardiac arrest) are now managed with implantable cardioverter defibrillators at almost all centers. There is little debate on this recommendation in the modern era of reliable transvenous devices (175). Even when catheter or surgical VT ablation has been tried with acute success, the recurrence risk for ablative therapy remains too uncertain (174) not to defer to an implantable cardioverter defibrillator in a patient who has clearly demonstrated the potential for life-threatening arrhythmias.

10.9.2. Reproduction

Pregnancy is not advised in patients with unrepaired tetralogy of Fallot. After repair of tetralogy of Fallot, the prognosis for a successful pregnancy is good provided there are no important hemodynamic residua and functional capacity is good. A comprehensive, informed cardiovascular evaluation is recommended before each pregnancy. Pregnancy is usually well tolerated even in the setting of severe pulmonary regurgitation, as long as RV function is no more than mildly depressed and sinus rhythm is maintained (550).

Patients with tetralogy of Fallot have an increased risk of fetal loss, and their offspring are more likely to have congenital anomalies than offspring in the general population, especially in the setting of a 22q11.2 microdeletion. Screening for 22q11.2 microdeletion should be considered in patients with conotruncal abnormalities before pregnancy to provide appropriate genetic counseling (69). In the absence of a 22q11 deletion, the risk of a fetus having CHD is approximately 4% to 6%. Fetal echocardiography should be offered to the mother in the second trimester.

10.9.3. Exercise

Recommendations are summarized by Task Force 1 of the 36th Bethesda Conference on CHD (3).

10.9.4. Endocarditis Prophylaxis

Refer to the AHA guidelines on endocarditis prophylaxis (72). Also, refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information.

11. Dextro-Transposition of the Great Arteries

11.1. Definition

TGA implies that each great artery arises from the wrong ventricle. TGA is AV concordance with ventriculoarterial discordance. As such, d-TGA implies that the aorta arises rightward and anterior to the pulmonary artery and arises from the systemic right ventricle.

11.2. Associated Lesions

Patients with d-TGA by definition have abnormal origins of the aorta and pulmonary artery. Anomalies of the coronary ostia are also common, and clear delineation is required. Additional congenital cardiac lesions include VSD, which occurs in up to 45% of cases, LVOT obstruction in approximately 25% of cases, and coarctation of the aorta in approximately 5%.

11.3. Clinical Course: Unrepaired

The infant with d-TGA will generally present with cyanosis, and some form of admixture of blood is required for survival. For the past 2 decades, ASO in the neonatal period has been the primary surgical repair of choice for uncomplicated d-TGA. In patients who present late (after 6 to 8 weeks of age), pulmonary artery banding to prepare the left ventricle is often necessary. Patients with d-TGA and associated VSD may undergo initial pulmonary artery banding or shunt procedure, depending on the presence or absence of subpulmonary artery obstruction. If there is an associated large VSD, a Rastelli procedure can be performed as a primary procedure. Initial presentation in adulthood would be rare unless the patient is from an underserved country and has the appropriate admixture of blood; usually, some form of VSD and pulmonic stenosis (tetralogy of Fallot physiology) or VSD with pulmonary vascular disease will be present with associated cyanosis.

11.4. Recommendation for Evaluation of the Operated Patient With Dextro-Transposition of the Great Arteries

CLASS I

1. Patients with repaired d-TGA should have annual follow-up with a cardiologist who has expertise in the management of ACHD patients. (*Level of Evidence: C*)

Most adults born with d-TGA will have had 1 or more operations in childhood. All patients should have regular follow-up with a cardiologist who has expertise in ACHD.

The frequency may be determined by the degree of residual hemodynamic abnormalities, and these become more common, along with the occurrence of arrhythmias, with advancing age.

All operated d-TGA patients should be seen at least annually by a specialist in an ACHD regional center, with attention given to rhythm disorders, as well as ventricular and valvular function. Stress testing, including cardiopulmonary stress testing, should be applied selectively. If specialized testing is performed, it is best done at a regional center. If significant abnormalities are uncovered by these examinations, or if the patient is symptomatic, more frequent follow-up visits are indicated.

11.4.1. Clinical Features and Evaluation of Dextro-Transposition of the Great Arteries After Atrial Baffle Procedure

Because the ASO only gained acceptance in the 1980s, many adults with d-TGA will have had a Mustard or Senning procedure. These procedures involve an atrial baffle that redirects the systemic venous blood to the mitral valve and left ventricle, which remains committed to the pulmonary artery. The pulmonary venous blood is redirected to the tricuspid valve and right ventricle, which remains committed to the aorta.

The atrial baffle (Mustard or Senning) procedure for d-TGA has characteristic late long-term problems. The most common early structural complications include baffle obstruction, which most commonly affects the superior limb rather than the inferior vena cava. Facial suffusion and "superior vena cava syndrome" may result. Inferior vena cava obstruction may cause hepatic congestion or even cirrhosis. Baffle leaks occur in up to 25% of patients. Most are small but may pose a risk of paradoxical embolus, particularly in the setting of atrial arrhythmias and an endocardial pacemaker. Pulmonary venous obstruction may also occur but is less common. Subpulmonary stenosis and PS may occur, in part related to the abnormal geometry of the left ventricle, which becomes distorted and compressed by the enlarged systemic right ventricle. Long term, the most important complication after atrial baffle is failure of the systemic right ventricle and systemic TR. These complications have a major impact on morbidity and mortality. Important but less common complications include PAH, residual VSD, dynamic subpulmonic stenosis, and a host of conduction and arrhythmia disturbances with the potential for implantation of permanent pacemakers or sudden death (37,108,111, 551–558).

11.4.2. Clinical Examination

The adult with a prior atrial baffle procedure may have a relatively normal examination. More commonly, features of RV enlargement and TR are present. A loud A_2 is usually present owing to the anterior position of the aorta and should not be confused with the loud P_2 of PAH. A harsh systolic murmur may be a feature of a residual VSD or subpulmonary stenosis. Heart failure with features of systemic TR occurs with increasing frequency with longer duration of follow-up. Sudden cardiac death also occurs in a small percentage of patients.

11.4.3. Electrocardiogram

The ECG demonstrates right-axis deviation and RV hypertrophy in patients with prior atrial baffle because the right ventricle is the SV. Bradycardia may represent a slow junctional rhythm or complete heart block. Rhythm abnormalities may be further elucidated by ambulatory rhythm monitoring (Holter or event recorder). Bradycardia and/or syncope may be presenting features related to sinus node dysfunction. Exercise testing to determine functional capacity and the potential for arrhythmias may be helpful.

11.4.4. Imaging for Dextro-Transposition of the Great Arteries After Atrial Baffle Procedure

A narrow mediastinal shadow is common on chest x-ray in patients with d-TGA because of the parallel relationship of the great arteries. Ventricular size and pulmonary markings depend on patient status but are normal in patients with preserved ventricular function.

11.4.4.1. Recommendations for Imaging for Dextro-Transposition of the Great Arteries After Atrial Baffle Procedure

CLASS I

1. **In patients with d-TGA repaired by atrial baffle procedure, comprehensive echocardiographic imaging should be performed in a regional ACHD center to evaluate the anatomy and hemodynamics. (*Level of Evidence: B*)**
2. **Additional imaging with TEE, CT, or MRI, as appropriate, should be performed in a regional ACHD center to evaluate the great arteries and veins, as well as ventricular function, in patients with prior atrial baffle repair of d-TGA. (*Level of Evidence: B*)**

CLASS IIa

1. **Echocardiography contrast injection with agitated saline can be useful to evaluate baffle anatomy and shunting in patients with previously repaired d-TGA after atrial baffle. (*Level of Evidence: B*)**
2. **TEE can be effective for more detailed baffle evaluation for patients with d-TGA. (*Level of Evidence: B*)**

Comprehensive echocardiography is the mainstay of anatomic and hemodynamic assessment in most d-TGA patients after atrial baffle (108,111,551) and should be performed in an experienced center. Evaluation for intra-atrial baffle anatomy and shunting or obstruction may warrant echocardiography contrast injection. Assessment of systemic RV function is challenging by echocardiography. In addition to routine evaluation of ventricular size and function, measurement of the dP/dt of the AV regurgitant jet, Doppler tissue indices of annular motion, and the myocardial performance index may provide further insight (108,111,194,551,559,560). Tissue Doppler evaluation of myocardial acceleration during isovolumic contraction has been validated as a sensitive, noninvasive method to assess RV contractility (561,562). The myocardial performance index has the advantage of representing indices of both systolic and diastolic function without geometric constraints and has shown a relationship to BNP

levels in ACHD patients (193). The coronary anatomy may be difficult to evaluate by echocardiography in the adult patient.

TEE is used to provide complementary information, including imaging of atrial anatomy, the presence of baffle leak or obstruction, and intracardiac thrombus. Radiological imaging with MRI or CT can be used to further assess atrial baffle patency, systemic ventricular function, and coronary anatomy.

MRI or magnetic resonance angiography is usually superior for evaluation of the extracardiac great arteries and veins. Comparison of TTE with cardiac MRI to assess ventricular function in adults after atrial baffle procedures has shown a good correlation between ventricular dimensions and function (563). MRI has also been shown to correlate closely with equilibrium radionuclide ventriculography assessment of RV ejection fraction (564). Current MRI techniques with first-pass, contrast-enhanced myocardial perfusion and myocardial delayed enhancement for viability, ischemia, and/or infarction are valuable tools (204).

11.4.5. Cardiac Catheterization

Cardiac catheterization is used to assess hemodynamics, baffle leak, superior vena cava or inferior vena cava pathway obstruction, pulmonary venous pathway obstruction, myocardial ischemia, unexplained systemic RV dysfunction, or significant LV stenosis (subpulmonary stenosis or LVOT obstruction) or to assess the PAH, with potential for vasodilator testing. Cardiac catheterization in patients after the atrial baffle procedure also provides the opportunity for intervention. For adults after palliative atrial baffle repair for d-TGA, VSD, and pulmonary vascular disease, catheterization may be indicated to assess the potential for pulmonary artery vasomodulator therapy.

11.5. Clinical Features and Evaluation of Dextro-Transposition of the Great Arteries After Arterial Switch Operation

The quality of life and health status of children 11 to 15 years of age after ASO are similar to those of normal children and significantly better than those of children who have undergone the atrial baffle procedure (565). In the current era, the preference is for an ASO, and the earliest survivors of this procedure are now adolescents and young adults (566,567). Long-term concerns after the ASO include coronary insufficiency, myocardial ischemia, ventricular dysfunction and arrhythmias, and issues regarding stenosis at the great arterial anastomotic sites, as well as development of aortic or pulmonary regurgitation. Significant neoaortic root dilatation and neoaortic valve regurgitation may develop over time, in part related to older age at the time of ASO or to an associated VSD with previous pulmonary artery banding (568).

11.5.1. Clinical Examination

Patients with prior ASO are now being seen in adult clinics. They may present with no specific findings on physical examination or with a systolic murmur related to arterial obstruction at the arterial anastomosis site. Diastolic murmurs of aortic or pulmonary regurgitation may be noted.

11.5.2. Electrocardiogram

The ECG should be normal in patients after ASO without residua. Ischemic ECG changes are occasionally noted at rest or may occur with exercise, which suggests compromise of the coronary ostia. This should be evaluated further. RV and LV hypertrophy may occur with outflow obstruction.

11.5.3. Chest X-Ray

The chest x-ray after uncomplicated ASO should be unremarkable. A narrow pedicle may be noted.

11.5.4. Recommendations for Imaging for Dextro-Transposition of the Great Arteries After Arterial Switch Operation

CLASS I

1. **Comprehensive echocardiographic imaging to evaluate the anatomy and hemodynamics in patients with d-TGA and prior ASO repair should be performed at least every 2 years at a center with expertise in ACHD. (*Level of Evidence: C*)**
2. **After prior ASO repair for d-TGA, all adults should have at least 1 evaluation of coronary artery patency. Coronary angiography should be performed if this cannot be established noninvasively. (*Level of Evidence: C*)**

CLASS IIa

1. **Periodic MRI or CT can be considered appropriate to evaluate the anatomy and hemodynamics in more detail. (*Level of Evidence: C*)**

Echocardiography after ASO may demonstrate minimal findings or 1 or more of the recognized complications after ASO, which include the following: 1) stenosis at the arterial anastomotic sites, most commonly PS (567); 2) aortic root dilatation; and 3) neoaortic valve regurgitation (native pulmonary valve) (569). Coronary complications cannot be assessed adequately by echocardiography, but stress echocardiography may facilitate detection of ischemia. CT angiography has been used recently. Patients with intramural or single coronary arteries have increased mortality compared with those with the typical coronary pattern (570).

11.5.5. Recommendation for Cardiac Catheterization After Arterial Switch Operation

CLASS IIa

1. **Coronary angiography is reasonable in all adults with d-TGA after ASO to rule out significant coronary artery obstruction. (*Level of Evidence: C*)**

Coronary ischemia is a recognized late complication after ASO, with concern about ischemia or infarction reported in up to 8% of patients after ASO. These complications are due to reimplantation of the coronary arteries during surgery (567). Noninvasive testing for coronary ischemia may not be sufficiently sensitive, and coronary arteriography has been recommended 5, 10, and 15 years after ASO to detect significant late coronary artery stenosis. Aortic root angiography is recommended to detect ostial coronary artery disease.

Hemodynamic cardiac catheterization is used to assess pulmonary and aortic anastomosis obstruction when incom-

pletely evaluated by other imaging modalities. Cardiac catheterization in patients after ASO also provides the opportunity for intervention.

11.6. Clinical Features and Evaluation: Dextro-Transposition of the Great Arteries After Rastelli Operation

The Rastelli operation for a combination of d-TGA, PS, and VSD has recognized complications that include RVOT or pulmonary conduit obstruction, superimposed RV failure, and TR. LVOT obstruction may also occur from the intraventricular baffle, arrhythmias from atriotomy and/or ventriculotomy incisions, residual VSD, myocardial hypertrophy, chamber enlargement, aortic root dilatation, and aortic valve regurgitation. The 3 most common late causes of postoperative death are sudden cardiac death, heart failure, and reoperation.

Patients who have undergone the Rastelli procedure may present with dyspnea, fatigue, or arrhythmias. As the pulmonary valve degenerates and becomes more obstructive, the A wave in the jugular venous pressure rises, an RV heave becomes apparent, and the murmur across the pulmonary valve becomes louder. The P_2 becomes quieter, and when the valve is severely calcified, it disappears entirely.

11.6.1. Electrocardiogram

The ECG in post-Rastelli patients often demonstrates right bundle-branch block. RV hypertrophy and progressive conduction disease may occur with time.

11.6.2. Chest X-Ray

The chest x-ray demonstrates a narrow pedicle with associated features of conduit replacement. Cardiac enlargement may occur with progressive valve disease.

11.6.3. Imaging

Echocardiography is the primary imaging modality in patients with prior Rastelli operation. Recurrent RV or LV outflow obstruction can usually be delineated adequately by echocardiography-Doppler examination. Assessment of RV pressure and the occurrence of conduit obstruction can be facilitated by measurement of TR velocity. Additional important features should include assessment of pulmonary regurgitation, residual or baffle-margin VSD, and development of PAH.

11.7. Recommendations for Diagnostic Catheterization for Adults With Repaired Dextro-Transposition of the Great Arteries

CLASS I

1. Diagnostic catheterization of the adult with d-TGA should be performed in centers with expertise in the catheterization and management of ACHD patients. (*Level of Evidence: C*)

CLASS IIa

1. For adults with d-TGA after atrial baffle procedure (Mustard or Senning), diagnostic catheterization can be beneficial to assist in the following:
   a. Hemodynamic assessment. (*Level of Evidence: C*)
   b. Assessment of baffle leak. (*Level of Evidence: B*)
   c. Assessment of superior vena cava or inferior vena cava pathway obstruction. (*Level of Evidence: B*)
   d. Assessment of pulmonary venous pathway obstruction. (*Level of Evidence: B*)
   e. Suspected myocardial ischemia or unexplained systemic RV dysfunction. (*Level of Evidence: B*)
   f. Significant LV outflow obstruction at any level (LV pressure greater than 50% of systemic levels, or less in the setting of RV dysfunction). (*Level of Evidence: B*)
   g. Assessment of PAH, with potential for vasodilator testing. (*Level of Evidence: C*)
2. For adults with d-TGA, VSD, and PS, after Rastelli-type repair, diagnostic catheterization can be beneficial to assist in the following:
   a. Coronary artery delineation before any intervention for RVOT obstruction. (*Level of Evidence: C*)
   b. Assessment of residual VSD. (*Level of Evidence: C*)
   c. Assessment of PAH, with potential for vasodilator testing. (*Level of Evidence: C*)
   d. Assessment of subaortic obstruction across the left ventricle–to-aorta tunnel. (*Level of Evidence: C*)

11.7.1. Problems and Pitfalls

The following are potential problems and pitfalls related to adults with d-TGA:

- Antiarrhythmic therapy, which might aggravate sinus node dysfunction in patients after atrial baffle operation, must be used cautiously.
- A detailed assessment of the atrial baffle for leak and obstruction must be undertaken before endocardial pacemaker implantation.
- There is potential for endocardial pacing leads to exacerbate obstruction in the atrial baffle.
- The absence of typical symptoms of coronary ischemia does not preclude the presence of important ostial coronary artery disease in patients with prior ASO.

11.8. Management Strategies

11.8.1. Medical Therapy

The role of medical treatment (eg, ACE inhibitors and beta blockers) to prevent or treat ventricular dysfunction has only been studied in small numbers, and its benefit is controversial (571–573). The role of ACE inhibitors and beta blockers remains uncertain, and beta blockers may precipitate complete AV block in patients with preexisting sinus node dysfunction. Therapy for heart failure now incorporates medications directed at the renin-angiotensin-aldosterone system.

11.8.2. Recommendations for Interventional Catheterization for Adults With Dextro-Transposition of the Great Arteries

CLASS IIa

1. Interventional catheterization of the adult with d-TGA can be performed in centers with expertise in the catheterization and management of ACHD patients. (*Level of Evidence: C*)

2. For adults with d-TGA after atrial baffle procedure (Mustard or Senning), interventional catheterization can be beneficial to assist in the following:
   a. Occlusion of baffle leak. (*Level of Evidence: B*)
   b. Dilation or stenting of superior vena cava or inferior vena cava pathway obstruction. (*Level of Evidence: B*)
   c. Dilation or stenting of pulmonary venous pathway obstruction. (*Level of Evidence: B*)
3. For adults with d-TGA after ASO, interventional catheterization can be beneficial to assist in dilation or stenting of supravalvular and branch pulmonary artery stenosis. (*Level of Evidence: B*)
4. For adults with d-TGA, VSD, and PS, after Rastelli-type repair, interventional catheterization can be beneficial to assist in the following:
   a. Dilation with or without stent implantation of conduit obstruction (RV pressure greater than 50% of systemic levels, or peak-to-peak gradient greater than 30 mm Hg; these indications may be lessened in the setting of RV dysfunction). (*Level of Evidence: C*)
   b. Device closure of residual VSD. (*Level of Evidence: C*)

Interventional catheterization plays an important role in the management of many adults with d-TGA after atrial baffle, ASO, or Rastelli-type repair. As in the management of all ACHD patients, a thorough understanding of baseline and modified anatomy, with awareness of the details of each modification, is requisite in the safe catheterization of each affected adult.

11.8.2.1. Interventional Catheter Options After Atrial Baffle

Successful balloon-expanded stent implantation for relief of symptomatic systemic or pulmonary venous baffle obstruction, as well as percutaneous placement of transcatheter implants for baffle leak elimination, has been reported in adult survivors of the atrial baffle for d-TGA. Percutaneous placement of transcatheter implants for pulmonary artery banding for improvement of systemic ventricular dysfunction or TR or in anticipation of late arterial switch remains to be tested.

11.8.2.2. Interventional Catheter Options After Arterial Switch Operation

Catheterization may be particularly useful in the assessment and therapy of coronary ischemia due to coronary artery stenosis and occlusion (refer to Section 8.0, Coronary Artery Abnormalities). Although reports exist of transcatheter dilation and stenting of central pulmonary artery stenosis after the LeCompte maneuver (translocation of the right pulmonary artery anterior to the aorta), the optimal indication for therapy and the means of intervention remain to be determined.

11.8.2.3. Interventional Catheter Options After Rastelli Repair

When branch pulmonary artery stenosis is present in adults with prior Rastelli repair of d-TGA, collaboration between a congenital cardiologist, interventional cardiologist, and congenital cardiac surgeon is recommended to determine the best treatment, which may include preoperative stenting, intraoperative stenting, or intraoperative patch with or without conduit replacement. Dilation with or without stent implantation of conduit obstruction may be indicated when the RV pressure is greater than 50% of systemic levels or the peak-to-peak gradient is greater than 50 mm Hg. These indications may be lessened in the setting of RV dysfunction. An attractive option is device closure of residual VSD when the VSD is causing hemodynamic impact.

11.8.3. Recommendations for Surgical Interventions

11.8.3.1. After Atrial Baffle Procedure (Mustard, Senning)

CLASS I

1. Surgeons with training and expertise in CHD should perform operations in patients with d-TGA and the following indications:
   a. Moderate to severe systemic (morphological tricuspid) AV valve regurgitation without significant ventricular dysfunction. (574) (*Level of Evidence: B*)
   b. Baffle leak with left-to-right shunt greater than 1.5:1, right-to-left shunt with arterial desaturation at rest or with exercise, symptoms, and progressive ventricular enlargement that is not amenable to device intervention. (*Level of Evidence: B*)
   c. Superior vena cava or inferior vena cava obstruction not amenable to percutaneous treatment. (*Level of Evidence: B*)
   d. Pulmonary venous pathway obstruction not amenable to percutaneous intervention. (*Level of Evidence: B*)
   e. Symptomatic severe subpulmonary stenosis. (*Level of Evidence: B*)

11.8.3.2. After Arterial Switch Operation

CLASS I

1. It is recommended that surgery be performed in patients after the ASO with the following indications:
   a. RVOT obstruction peak-to-peak gradient greater than 50 mm Hg or right ventricle/left ventricle pressure ratio greater than 0.7, not amenable or responsive to percutaneous treatment; lesser degrees of obstruction if pregnancy is planned, greater degrees of exercise are desired, or concomitant severe pulmonary regurgitation is present. (*Level of Evidence: C*)
   b. Coronary artery abnormality with myocardial ischemia not amenable to percutaneous intervention. (*Level of Evidence: C*)
   c. Severe neoaortic valve regurgitation. (*Level of Evidence: C*)
   d. Severe neoaortic root dilatation (greater than 55 mm) after ASO. (575) (This recommendation is based on data for other forms of degenerative aortic root aneurysms). (*Level of Evidence: C*)

11.8.3.3. After Rastelli Procedure

CLASS I

1. Reoperation for conduit and/or valve replacement after Rastelli repair of d-TGA is recommended in patients with the following indications:
   a. Conduit obstruction peak-to-peak gradient greater than 50 mm Hg. (*Level of Evidence: C*)
   b. RV/LV pressure ratio greater than 0.7. (*Level of Evidence: C*)
   c. Lesser degrees of conduit obstruction if pregnancy is being planned or greater degrees of exercise are desired. (*Level of Evidence: C*)

d. Subaortic (baffle) obstruction (mean gradient greater than 50 mm Hg). (*Level of Evidence: C*)
e. Lesser degrees of subaortic (baffle) obstruction if LV hypertrophy is present, pregnancy is being planned, or greater degrees of exercise are desired. (*Level of Evidence: C*)
f. Presence of concomitant severe AR. (*Level of Evidence: C*)

2. Reoperation for conduit regurgitation after Rastelli repair of d-TGA is recommended in patients with severe conduit regurgitation and the following indicators:
a. Symptoms or declining exercise tolerance. (*Level of Evidence: C*)
b. Severely depressed RV function. (*Level of Evidence: C*)
c. Severe RV enlargement. (*Level of Evidence: C*)
d. Development/progression of atrial or ventricular arrhythmias. (*Level of Evidence: C*)
e. More than moderate TR. (*Level of Evidence: C*)
3. Collaboration between surgeons and interventional cardiologists, which may include preoperative stenting, intraoperative stenting, or intraoperative patch angioplasty with or without conduit replacements, is recommended to determine the most feasible treatment for pulmonary artery stenosis. (*Level of Evidence: C*)
4. Surgical closure of residual VSD in adults after Rastelli repair of d-TGA is recommended with the following indicators:
a. Qp/Qs greater than 1.5:1. (*Level of Evidence: B*)
b. Systolic pulmonary artery pressure greater than 50 mm Hg. (*Level of Evidence: B*)
c. Increasing LV size from volume overload. (*Level of Evidence: C*)
d. Decreasing RV function from pressure overload. (*Level of Evidence: C*)
e. RVOT obstruction (peak instantaneous gradient greater than 50 mm Hg). (*Level of Evidence: B*)
f. Pulmonary artery pressure less than two thirds of systemic pressure, or PVR less than two thirds of systemic vascular resistance, with a net left-to-right shunt of 1.5:1, or a decrease in pulmonary artery pressure with pulmonary vasodilators (oxygen, nitric oxide, or prostaglandins). (*Level of Evidence: B*)
5. Surgery is recommended after Rastelli repair of d-TGA in adults with branch pulmonary artery stenosis not amenable to percutaneous treatment. (*Level of Evidence: C*)
6. In the presence of a residual intracardiac shunt or significant systemic venous obstruction, permanent pacing, if indicated, should be performed with epicardial leads. (574) (*Level of Evidence: B*)

CLASS IIa

1. A concomitant Maze procedure can be effective for the treatment of intermittent or chronic atrial tachyarrhythmias in adults with d-TGA requiring reoperation for any reason. (*Level of Evidence: C*)

11.8.3.4. Reoperation After Atrial Baffle Procedure

Late survival after atrial baffle is approximately 65% at 25 years; survival is approximately 80% for "simple" TGA and 45% for those with "complex" d-TGA (ie, those with a VSD or PS) (576). Reoperation after the atrial baffle procedure in adults is recommended for patients with a baffle leak that is not amenable to device intervention, demonstrates a left-to-right shunt greater than 1.5:1 or a right-to-left shunt with arterial desaturation at rest or with exercise, is associated with symptoms, or progressive ventricular enlargement. Although late conversion to an ASO has been attempted in some centers, it has not proved successful and is not generally considered a reasonable option for the management of systemic ventricular failure in patients with TGA.

Patients with severe symptomatic superior or inferior vena cava obstruction or pulmonary venous pathway obstruction not amenable to percutaneous treatment should be referred for operative intervention. Patients with severe symptomatic subpulmonary stenosis should also be considered for operative intervention.

Severe symptomatic systemic AV (morphological tricuspid) valve regurgitation may prompt surgical referral when the problem relates to intrinsic tricuspid valve disease and is not secondary to systemic ventricular dysfunction. This is a rare occurrence, because most TR after atrial baffle procedure is secondary to systemic ventricular dysfunction. Alternative techniques include tricuspid valve replacement, pulmonary artery band placement, and transplantation.

11.8.3.5. Reoperation After Arterial Switch Operation

Late survival after the ASO is approximately 90% at 10 years. A small risk of progressive aortic root dilation is present late after ASO (577).

Reoperation after ASO should be considered for adults with the following: severe RVOT obstruction peak-to-peak gradient greater than 50 mm Hg or RV/LV pressure ratio greater than 0.7, not amenable or responsive to percutaneous treatment, or lesser degrees of obstruction that are dynamic if pregnancy is planned or greater degrees of exercise are desired. Pulmonary valve replacement or repair should be considered when severe pulmonary regurgitation is present and there is significant RV dilatation or RV dysfunction.

Coronary ostial stenosis late after the ASO may be repaired by coronary bypass grafting or ostial arterioplasty techniques. Patients who have developed neoaortic root dilation without severe AR may be treated with valve-sparing root-replacement techniques when the aortic root diameter is greater than 55 mm.

11.8.3.6. Reoperation After Rastelli Repair

Late survival after the Rastelli procedure is approximately 60% at 20 years. Complications that may require reoperation or intervention are expected (453,578–580).

Reoperation after the Rastelli procedure for d-TGA in adults should be considered for severe symptomatic conduit obstruction with a peak gradient greater than or equal to 50 mm Hg, or lesser degrees of obstruction if pregnancy is being planned or greater degrees of exercise are desired, if the RV/LV pressure ratio is greater than 0.7, or in the setting of RV dysfunction. Severe conduit regurgitation after Rastelli repair should prompt consideration for reoperation for symptoms or decreased exercise tolerance, severely depressed RV function, severe RV enlargement, development/progression of atrial or ventricular arrhythmias, and more than moderate TR.

Relief of severe symptomatic subaortic (baffle) obstruction with a mean gradient greater than 50 mm Hg, or for lesser degrees of obstruction if LV hypertrophy is present, preg-

nancy is being planned, or greater degrees of exercise are desired. Occasionally, AVR is required for severe symptomatic AR. Closure of a residual VSD after Rastelli repair should be considered if there is a Qp/Qs greater than 1.5:1, systolic pulmonary artery pressure greater than 50 mm Hg, increasing left-sided heart size from volume overload, decreasing RV function from pressure overload, pulmonary artery pressure greater than two thirds of systemic pressure, or PVR less than two thirds of systemic vascular resistance with a net left-to-right shunt of 1.5:1 or a decrease in pulmonary artery pressure with pulmonary vasodilators (oxygen, nitric oxide, or prostaglandins). Occasionally, reoperation after Rastelli repair of d-TGA in adults with branch pulmonary artery stenosis not amenable to percutaneous treatment is recommended.

11.8.3.7. Other Reoperation Options

A concomitant Maze procedure can be effective for the treatment of intermittent or chronic atrial tachyarrhythmias in adults with d-TGA who are undergoing reoperation. This option for arrhythmia management should be considered preoperatively.

Cardiac transplantation may be required in failing systemic ventricular circulations; given that there are frequently anomalous venous or arterial connections, cardiac malpositioning, or both, technical anastomotic issues are common (581). In addition, many patients have had multiple surgeries and have more adhesions, which makes postoperative bleeding more of a concern, with the need for more blood transfusions and consequently more antigenic exposure, which leads to accelerated rejection.

11.9. Recommendations for Electrophysiology Testing/Pacing Issues in Dextro-Transposition of the Great Arteries

CLASS I

1. **Clinicians should be mindful of the risk of sudden arrhythmic death among adults after atrial baffle repair of d-TGA. These events usually relate to VT but may be caused in some cases by rapidly conducted IART or progressive AV block. (*Level of Evidence: B*)**
2. **Consultation with an electrophysiologist who is experienced with CHD is recommended to assist with treatment decisions. (*Level of Evidence: B*)**
3. **Pacemaker implantation is recommended for patients with d-TGA with either symptomatic sinus bradycardia or sick sinus syndrome. (*Level of Evidence: B*)**

CLASS IIa

1. **Routine surveillance with history, ECG, assessment of RV function, and periodic Holter monitoring can be beneficial as part of routine follow-up. (*Level of Evidence: B*)**

Predictors of sudden cardiac death after atrial baffle operations include symptoms from arrhythmias or heart failure and a history of documented arrhythmias, including atrial flutter or fibrillation (582). Whether electrophysiological and mapping studies with ablation of atrial flutter or fibrillation (which are frequently due to ventricular dysfunction) are protective is unknown. Pacing has not been found to be protective, and drug therapy (other than digoxin) is relatively unexplored; most (81%) sudden death events have occurred during exercise. When a rhythm has been recorded during sudden cardiac death, it is most often VT or ventricular fibrillation (582).

The most significant arrhythmia issue facing adults with d-TGA is the high incidence of tachy-brady syndrome that occurs in those who have undergone the Mustard or Senning operations (144). There is little doubt that these arrhythmias relate directly to the extensive suture lines created during atrial baffling, because the problem has largely disappeared in patients managed with the ASO. Some degree of sinus node dysfunction will be observed in more than half of the Mustard and Senning populations by the time they reach adulthood, probably due to surgical trauma in the vicinity of the sinus node or its arterial supply during creation of the superior vena cava limb of the atrial baffle (144). In addition, up to 30% of these patients will develop episodic IART or atrial flutter, which typically involves a macroreentry circuit around the atrial border of the tricuspid valve that is supported by the narrow conduction corridor between the inferior vena cava limb of the baffle and the valve ring (583). Patients can become highly symptomatic from either tachycardia or bradycardia, including the possibility of sudden death due to an episode of rapidly conducted IART (150). In patients who have advanced dysfunction of their systemic right ventricle, ventricular arrhythmias may also develop.

Treatment of tachy-brady syndrome in this setting can be quite challenging. As discussed in Section 1, options include pacemaker implantation for the bradycardia component (584), and for the tachycardia component, any combination of catheter ablation (147,159,583), drug therapy (149), or an automatic atrial antitachycardia pacemaker (155,584). For patients viewed as being at risk for serious ventricular arrhythmias or those resuscitated from a cardiac arrest, implantation of a defibrillator may be necessary. It should be emphasized that insertion of transvenous pacemaker or defibrillator leads in d-TGA patients after the Mustard or Senning operation involves unconventional lead routes and tip-fixation sites due to the complex atrial baffling. Operators need to have a clear understanding of the surgical anatomy before attempting such implants.

11.10. Key Issues to Evaluate and Follow-Up

11.10.1. Recommendations for Endocarditis Prophylaxis

CLASS IIa

1. **Antibiotic prophylaxis before dental procedures that involve manipulation of gingival tissue or the periapical region of teeth or perforation of the oral mucosa is reasonable in those with the following indications:**
   a. **Prosthetic cardiac valve. (*Level of Evidence: B*)**
   b. **Previous IE. (*Level of Evidence: B*)**
   c. **Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: B*)**

d. Completely repaired CHD with prosthetic materials, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure. (*Level of Evidence: B*)
e. Repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device that inhibit endothelialization. (*Level of Evidence: B*)

2. It is reasonable to consider antibiotic prophylaxis against IE before vaginal delivery at the time of membrane rupture in select patients with the highest risk of adverse outcomes. This includes patients with the following indications:
   a. Prosthetic cardiac valve or prosthetic material used for cardiac valve repair. (*Level of Evidence: C*)
   b. Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: C*)

CLASS III

1. Prophylaxis against IE is not recommended for nondental procedures (such as esophagogastroduodenoscopy or colonoscopy) in the absence of active infection. (*Level of Evidence: C*)

11.10.2. Recommendation for Reproduction

CLASS I

1. Before women with d-TGA contemplate pregnancy, a comprehensive clinical, functional, and echocardiographic evaluation should be performed at a center with expertise in ACHD. (*Level of Evidence: C*)

Comprehensive evaluation is recommended before pregnancy in all patients with d-TGA and prior repair. For patients after atrial baffle, major prepregnancy concerns include ventricular function assessment, systemic AV regurgitation, and atrial arrhythmias. There is a small but recognized risk of cardiovascular complications during pregnancy after the atrial baffle procedure. The physiological stresses of pregnancy, although clinically well tolerated late after a Mustard procedure, carry an increased risk of RV dysfunction that may be irreversible (585).

After a Rastelli operation, pregnancy should be well tolerated, assuming the absence of LV or RV obstruction and preservation of ventricular function. Isolated reports are available on the outcome of pregnancy after ASO. In the absence of important cardiovascular residua, pregnancy is well tolerated. A comprehensive anatomic and functional assessment, including assessment of coronary artery anatomy, is recommended before a patient proceeds with pregnancy.

11.10.3. Activity and Exercise

Patients with prior atrial baffle and Rastelli operation should be counseled to avoid strenuous and isometric exercise due to the risk of arrhythmias. Patients with prior ASO can participate in strenuous athletics if there is no evidence of important residua, including coronary artery complications.

12. Congenitally Corrected Transposition of the Great Arteries

12.1. Definition

CCTGA is a complex congenital anomaly with a wide spectrum of morphological features and clinical profiles. The underlying abnormality consists of AV discordance and ventricular-arterial discordance; thus, the right atrium connects to the morphological left ventricle, which gives rise to the pulmonary artery, and the left atrium connects to the morphological right ventricle, which gives rise to the aorta (586). The morphological right ventricle therefore functions as the SV, whereas the morphological left ventricle functions as the pulmonary ventricle. The term "corrected" refers to the physiologically normal direction of blood flow caused by this "double discordance," which makes the term "corrected" misleading (587). The term "l-transposition" is synonymous with CCTGA and indicates that the morphological RV is to the left of the morphological LV. In addition, the aorta is usually anterior to and to the left of the pulmonary artery. The AV valve that enters the SV is morphologically tricuspid and to avoid confusion is often designated the systemic AV valve (SAVV). Similarly, the AV valve entering the pulmonary ventricle is a morphological mitral valve and may be called the pulmonary AV valve. Ninety-five percent of cases occur in situs solitus (588). The coronary arteries and the ventricles are morphologically concordant, so a relatively thick-walled morphological right ventricle is supplied by a right coronary artery (589). The apex of the heart is usually in the left side of the chest (levocardia) but may be in the midline (mesocardia) or in the right side of the chest (dextrocardia) in approximately 20% of cases.

12.2. Associated Lesions

Only 1% of cases are uncomplicated, that is, they do not have associated anomalies. Frequently associated structural anomalies include the following:

- VSD occurs in 70% of patients and is usually perimembranous.
- PS occurs in 40% of patients and is often subvalvular.
- Some abnormality of the SAVV occurs in 90% of patients. Most commonly, this is an Ebstein-like malformation in which the valve is displaced inferiorly toward the cardiac apex (590).

The AV node and His bundle are often in an unusual position, and an accessory AV node is present in many patients (180). Conduction abnormalities are also common, with spontaneous complete heart block occurring at a rate of approximately 2% per year, and they are related to the abnormal position of the AV node (180,591,592). Complete AV block is common after surgical repair of a VSD or SAVV replacement, because the His bundle usually passes along the rim of the VSD.

12.3. Clinical Course

The adult with CCTGA presents in various ways, and the clinical course is quite variable depending on the presence and severity of associated lesions (593).

12.3.1. Presentation in Adulthood: Unoperated

Some patients were diagnosed in childhood but did not require operation. In some adults, the diagnosis is made for the first time because of a heart murmur or incidentally when an ECG, chest x-ray, or echocardiogram is performed for

other reasons (593). The diagnosis is often missed in cardiology practice because of the failure to recognize the abnormal position of the ventricles and the associated AV valves (594).

A subset of patients is correctly diagnosed for the first time in adulthood, most of whom have SAVV regurgitation. In 1 cohort, the initial diagnosis was not made until adulthood in 66% of patients, 17% of whom were more than 60 years old at the time of diagnosis (594). Patients may be asymptomatic but more often present with congestive heart failure, commonly with associated SAVV regurgitation. Symptoms include fatigue, dyspnea, and palpitation or syncope from atrial fibrillation or flutter or complete AV block. Those with a VSD and PS may have progressive cyanosis.

Many adult patients have advanced systemic ventricular dysfunction at the time of referral to a tertiary care center. Often, they have had severe SAVV regurgitation for more than 6 months and documented symptoms of heart failure or an SV ejection fraction less than 45% for more than 6 months (594). This is in distinct contrast to the accepted guidelines for patients with mitral regurgitation, even though patients with normal AV connections are less fragile than their counterparts with discordant AV connections.

In the majority of patients, the SAVV is morphologically abnormal, and with time, there is increasing regurgitation. In addition, as the SV dilates, the annulus also dilates, which causes failure of leaflet coaptation and progressive regurgitation. The interrelationship of SAVV regurgitation and ventricular function is complex. In most cases, ventricular dysfunction appears to be related to SAVV regurgitation. Although it is difficult to determine whether ventricular dysfunction is the initial culprit, evidence suggests that in the absence of associated congenital anomalies, primary SV failure is uncommon but is a frequent sequel to SAVV regurgitation. In one study of 40 patients, the only independent significant predictor of death was the presence of at least moderately severe TR, and in turn, only the presence of a morphologically abnormal SAVV predicted SAVV regurgitation (595). Progression of SAVV regurgitation may also occur as a result of pacemaker implantation, probably related to septal shift and further distortion of the SAVV annulus. Intracardiac repair of other lesions (eg, VSD) may also exacerbate SAVV regurgitation, probably by the same mechanism. It has been proposed that the SAVV should always be replaced if the regurgitation is more than grade 2/4 at the time of intracardiac repair of other lesions (596).

Although the morphological right ventricle may not be intrinsically suited to function long term as a systemic pump, survival to the seventh and eighth decade of life has been reported. Even in the absence of associated lesions, however, such survival is uncommon and invariably occurs in those in whom no operation has been performed. In a multicenter study of 182 patients with CCTGA, by age 45 years, 67% of patients with associated lesions had congestive heart failure, and 25% of patients without significant associated lesions had congestive heart failure (597). The exact mechanism of SV failure is unknown but may relate to microscopic structural features and fiber orientation of the RV myocardium. Other possibilities include coronary perfusion mismatch, because the cardiac hypertrophy caused by the added pressure load on the morphological right ventricle may outstrip the coronary artery oxygen supply, which comes mainly from the right coronary artery (598). A high incidence of myocardial perfusion defects with regional wall-motion abnormalities and impaired ventricular contractility has been reported (599). Positron emission tomography studies of blood flow measurements have also suggested that coronary reserve is decreased in the absence of ischemic symptoms in patients with CCTGA (454). Thus, there is a concept of mismatched myocardial demand (related to the hypertrophy and increased myocardial mass) and the blood supply from the single right coronary artery. Certainly, SV failure is a major cause of morbidity and mortality in the adult (49), and in 1 series was the cause of death in more than 50% of patients (600).

Atrial tachyarrhythmias are also common and occurred in 36% of survivors in the series reported by Connelly et al (600). They are more common in those with SV dysfunction and SAVV regurgitation and should be dealt with expeditiously.

12.4. Clinical Features and Evaluation of the Unoperated Patient

12.4.1. Clinical Examination

The clinical features depend on the presence or absence of associated lesions. Those with no associated lesions may have subtle findings of an abnormal ventricular impulse with an RV parasternal lift and a palpable second sound (loud A_2) that relates to the anterior aorta. When AV valve regurgitation develops, a holosystolic murmur is audible at the apex or lower left sternal border. Those with PS will have an ejection systolic murmur at the left sternal border, often in the third interspace. Patients with a VSD will have a holosystolic murmur similar to those patients with normal connections. Patients with a VSD and PS may have cyanosis. The diagnosis should always be considered in the setting of dextrocardia.

12.4.2. Electrocardiogram

The PR interval, which extends from the beginning of the P wave to the inscription of the R wave, is often prolonged, and there may be complete heart block (incidence of 2% per year). Because the right and left bundle branches are inverted, septal activation occurs from right to left, so that Q waves are absent in the left precordial leads but often present in the inferior leads III and AVF, as well as V_1. This may be misdiagnosed as inferior infarction.

12.4.3. Exercise Testing

Exercise testing helps to provide an objective assessment of functional capacity. Serial evaluations facilitate detection of functional decline, although patients may report that they are "normal." One study (52) showed that peak oxygen uptake ($\dot{V}o_2$ max) in a group of 41 patients with CCTGA ranged from 11 to 22 mL per kg per min, which is the equivalent of only 30% to 50% of normal control values.

12.4.4. Chest X-Ray

Because of the abnormal relationship of the aorta and pulmonary artery, the vascular pedicle looks abnormal, often appearing narrow and straight. The ascending aorta is not visible on the right, and the descending aorta and pulmonary artery may not be visible on the left. The ventricular silhouette has a "humped" appearance (601). In the presence of SAVV regurgitation and ventricular dysfunction, the heart may be enlarged. Dextrocardia also occurs with CCTGA, and if the chest x-ray reveals the gastric bubble on the left (abdominal situs solitus) and the apex of the heart on the right, CCTGA should be suspected.

12.4.5. Two-Dimensional Echocardiography

Two-dimensional echocardiography facilitates detection of AV discordance and ventriculoarterial discordance (602). The determination of ventricular morphology is best assessed by the AV valves, because a tricuspid valve always enters a morphological right ventricle. In the apical 4-chamber view, the tricuspid valve is always the most inferior valve (closer to the cardiac apex). In addition, it has chordal attachments to the inlet septum and can be differentiated from the mitral valve by the absence of distinct papillary muscle attachments. Malformations of the morphological tricuspid valve (eg, SAVV) can also be seen, the most common being an Ebstein-like abnormality with marked inferior displacement of the SAVV. This is very different from the classic Ebstein anomaly of the right AV valve, however, because there is no large "sail-like" anterior leaflet and no atrialized portion of the ventricle. In the short axis, the tricuspid valve can be shown to be trileaflet rather than having the bileaflet "fish mouth" appearance of the mitral valve in diastole. The abnormal great arterial relationship can also be shown in this view because the aorta lies anterior and to the left of the pulmonary artery.

Other defects can also be detected by 2-dimensional echocardiography. If a VSD is present, it is usually in the perimembranous region and may extend into the inlet septum. Abnormalities of the pulmonary valve can also be seen, which often coexist with obstruction in the subpulmonary region: either an aneurysm of the membranous septum, a fibrous membrane, or mobile subpulmonary tissue "tags," which also contribute to obstruction. Assessment of RV function is much more difficult than assessment of LV function because of its more complex shape, and this is equally true when the right ventricle is the SV.

12.4.6. Magnetic Resonance Imaging

The reference standard for assessing function is generally accepted as being MRI, which permits multiple "slices" through the ventricle to assess end-diastolic and end-systolic volumes to be measured and an ejection fraction calculated. Edge detection is currently made by hand, so errors in the technique are still inherent, but automated methods of edge detection are under development. MRI is not available in all centers, however, and is precluded in the presence of a pacemaker. Echocardiography is still the most commonly used imaging modality and will provide a reasonable assessment of ventricular function in experienced hands.

12.4.7. Cardiac Catheterization

Cardiac catheterization will facilitate evaluation of ventricular function and the degree of SAVV regurgitation if there is doubt after noninvasive studies. In the setting of depressed ventricular function, significant SAVV regurgitation should be ruled out in all cases. A hemodynamic assessment of other associated anomalies can be performed in addition to a measurement of associated PAH and pulmonary resistance.

12.5. Recommendations for Evaluation and Follow-Up of Patients With Congenitally Corrected Transposition of the Great Arteries

CLASS I

1. **All patients with CCTGA should have a regular follow-up with a cardiologist who has expertise in ACHD. (*Level of Evidence: C*)**
2. **Echocardiography-Doppler study and/or MRI should be performed yearly or at least every other year by staff trained in imaging complex CHD. (*Level of Evidence: C*)**
3. **The following diagnostic evaluations are recommended for patients with CCTGA:**
   a. **ECG. (*Level of Evidence: C*)**
   b. **Chest x-ray. (*Level of Evidence: C*)**
   c. **Echocardiography-Doppler study. (*Level of Evidence: C*)**
   d. **MRI. (*Level of Evidence: C*)**
   e. **Exercise testing. (*Level of Evidence: C*)**

The frequency of follow-up visits may be determined by the presence or absence of associated lesions but is often annual. More frequent visits may be necessary for those with ventricular dysfunction and SAVV regurgitation, regardless of whether they are symptomatic. Clinical examination, ECG, chest x-ray, and cardiopulmonary exercise testing will usually be performed. If progression of heart block is suspected by history or ECG, ambulatory ECG monitoring for 24 hours should be considered. Patients who have implantation of an endocardial pacemaker warrant more frequent observation, because septal shift may cause deterioration in SV dysfunction.

12.6. Key Issues of Unoperated Patients

Key issues for patients who have never had surgery and those who have previously had reparative surgery are listed below.

Unrepaired Patients:

- There is a potential for failure to make the diagnosis.
- CCTGA should always be considered in the presence of dextrocardia, particularly when the gastric bubble is on the left and the cardiac apex is on the right.
- Symptoms and functional status should be assessed (exercise testing should be used to assess functional capacity).
- Function of the SV should be monitored.
- Significant SAVV regurgitation should be excluded in the presence of SV dysfunction.
- The patient should be referred for early SAVV replacement before SV function deteriorates. Operative intervention should be performed before the ejection fraction is less than 45%.
- An underlying hemodynamic abnormality (often SAVV regurgitation) should be sought when arrhythmias develop.

- Caution should be used with the dosage of antiarrhythmic therapy, and the risk of complete AV block should be considered.

Previously Repaired Patients:

- SV function should be monitored.
- Follow-up of SAVV prosthetic function should be conducted.
- Conduit function should be monitored.
- Aortic valve regurgitation should be monitored.
- Surveillance should be used for arrhythmias, both atrial and ventricular. Periodic Holter monitoring should be used to look for problems with AV conduction. Sinus rhythm should be maintained when possible.

12.7. Management Strategies

Medical therapy is usually related to the management of arrhythmias and treatment of ventricular dysfunction. Arrhythmia management is generally the same as for other forms of acquired heart disease, with concern about the potential for proarrhythmia and the negative inotropic potential of some drugs. It is prudent to start antiarrhythmic therapy relatively slowly because of the potential for complete AV block and the possible need for pacemaker implantation.

Treatment for SV dysfunction is appropriate, as for other forms of cardiomyopathy, but with important caveats. It is tempting to extrapolate treatment outcomes from other acquired causes of LV dysfunction to patients with systemic right ventricles such as CCTGA, but there are few evidence-based data to support the use of any drugs in this setting (572,573). Afterload reduction with ACE inhibitors or angiotensin II receptor blockers may be less successful than when used for a morphological left ventricle (603). Data are lacking to support the use of beta blockers to improve ventricular function in CCTGA, and caution must be used with dosage because of the propensity for complete AV block. Decline in SV function should prompt a careful search for SAVV regurgitation. Cardiac transplantation may be necessary in those with severe SV dysfunction refractory to medical therapy.

12.8. Interventional Therapy

12.8.1. Recommendations for Catheter Interventions

CLASS IIa

1. For patients with unrepaired CCTGA, cardiac catheterization can be effective to assess the following:
   a. Hemodynamic status in the setting of arrhythmia. (*Level of Evidence: C*)
   b. Unexplained SV dysfunction, to define the degree of systemic AV valve regurgitation, degree of intracardiac shunting, and coronary artery anatomy. (*Level of Evidence: C*)
   c. Unexplained volume retention or cyanosis, especially when noninvasive assessment of pulmonary outflow obstruction is limited. (*Level of Evidence: C*)

Combined with noninvasive imaging techniques, diagnostic and interventional cardiopulmonary catheterization play important roles in the management of many adults with CCTGA, both in the unoperated native state and after surgical repair with VSD patch or Rastelli-type LV–pulmonary artery connections. In addition, catheter-based hemodynamic assessment may be indicated more frequently in patients undergoing relatively pioneering surgical interventions (such as combined atrial switch and great ASO), in an attempt to provide the best care when optimal follow-up surveillance strategies have not yet been defined.

12.8.2. Initial Surgical Repair

Surgical repair in infants and children often aims at restoring the left ventricle as the SV. The indications for surgery in adult patients are usually the onset of symptoms due to associated SAVV regurgitation or SV dysfunction and rarely due to pulmonary overcirculation. Surgical intervention in the adult, therefore, often consists of SAVV replacement alone and ideally should be performed before the SV ejection fraction has deteriorated below 45% (604). In some circumstances, consideration may be given to restoring the left ventricle to the SV, but careful evaluation of its function must be made, because anatomic repair in adults is associated with a higher mortality. In cases in which there is an unrestrictive VSD and LV function is normal, an anatomic repair should be considered. Atrium-level switch of venous return must also be done with the Mustard or Senning procedure, with all the potential for late complications already recognized in patients with d-TGA who have had these procedures. If the VSD is unrestrictive and is located in the conoventricular septum, adjacent to the tricuspid valve, then a Rastelli type of reconstruction for the LV outflow can be done by baffling the VSD to the leftward and anterior aorta. Right ventricle–to–pulmonary artery continuity is achieved with a conduit. A nonanatomic repair may also be considered, which would consist of closure of the VSD, relief of PS if present, and replacement of the SAVV in the setting of SAVV regurgitation. It has been suggested that the SAVV should be replaced at the time of surgery if any more than mild SAVV regurgitation is present. The nonanatomic repair should be considered a temporizing procedure, because the patients remain at significant risk for right systemic ventricle dysfunction.

12.8.3. Recommendations for Surgical Intervention

CLASS I

1. Surgeons with training and expertise in CHD should perform operations for patients with CCTGA for the following indications:
   a. Unrepaired CCTGA and severe AV valve regurgitation. (*Level of Evidence: B*)
   b. Anatomic repair with atrial and arterial level switch/Rastelli repair in cases in which the left ventricle is functioning at systemic pressures. (*Level of Evidence: B*)
   c. Simple VSD closure when the VSD is not favorable for LV-to-aorta baffling or is restrictive. (*Level of Evidence: B*)
   d. LV–to–pulmonary artery conduit in rare cases with LV dysfunction and severe LV outflow obstruction. (*Level of Evidence: B*)
   e. Evidence of moderate or progressive systemic AV valve regurgitation. (*Level of Evidence: B*)

f. Conduit obstruction with systemic or nearly systemic RV pressures and/or RV dysfunction after anatomic repair. (*Level of Evidence: B*)
g. Conduit obstruction and systemic or suprasystemic LV pressures in a patient with nonanatomic correction. (*Level of Evidence: B*)
h. Moderate or severe AR/neo-AR and onset of ventricular dysfunction or progressive ventricular dilatation. (*Level of Evidence: B*)

Indications for surgery in patients who have undergone previous operations include repair or replacement of the SAVV when a nonanatomic repair has been done previously, conduit replacement in patients who had a Rastelli-type anatomic repair, and resection of LV outflow obstruction in the same group. Aortic valve and mitral valve repair/replacement are occasionally required in patients who have undergone anatomic repair. AR is seen more commonly in patients who underwent pulmonary artery banding before ASO as part of staged anatomic repair.

Surgery for patients with CCTGA, whether or not they have had previous surgery, should be done at a center with experience in surgery for ACHD patients and by a surgeon with experience performing these types of operations who is familiar with the anatomic variability and atrium-level switch procedures.

12.8.4. Problems and Pitfalls

The following are problems and pitfalls for patients with corrected transposition:

- Failure to make the diagnosis
- Late referral in the setting of severe SAVV regurgitation and SV dysfunction
- Progression of SAVV regurgitation and SV dysfunction after implantation of a pacemaker.

12.9. Arrhythmias/Pacemaker/Electrophysiology Testing

CCTGA is associated with displacement of the AV node away from Koch's triangle to an anterior/superior position within the right atrium (180). Functional properties of these displaced conduction tissues can be suboptimal. Spontaneous complete heart block may be present from birth in approximately 4% of cases (600), and the conduction tissues are not infrequently traumatized during attempts at surgical repair. In addition, progressive deterioration in AV conduction can occur throughout life, with an estimated risk of spontaneous heart block of 2% per year (591). The status of AV conduction must be monitored regularly with ECG and periodic Holter monitoring in adults with CCTGA. Accessory pathways are also somewhat common in this condition, particularly when there is Ebstein malformation of the left-sided tricuspid valve (143).

Pacing may also be associated with septal shift, which may exacerbate SV dilatation and cause worsening of SAVV regurgitation. It is probably prudent, therefore, to have more frequent clinical and echocardiographic monitoring in an unoperated patient after pacemaker implantation (605).

12.10. Recommendations for Postoperative Care

CLASS I

1. Patients with prior repair of CCTGA should have regular follow-up with a cardiologist with expertise in ACHD. (*Level of Evidence: C*)
2. Echocardiography-Doppler study and/or MRI should be performed yearly or at least every other year by staff trained in imaging complex CHD. (*Level of Evidence: C*)

Regular follow-up (usually annually) is necessary (606), with particular emphasis on the following:

- Function of the SV
- Maintenance of sinus rhythm when possible
- Function of the SAVV or SAVV prosthesis if present
- Function of the pulmonary conduit or prosthesis
- Residual septal defects
- Development or progression of AR
- Degree of PAH, if any.

Some patients have had previous repair in childhood for lesions that were hemodynamically significant. One study of 111 children having surgical repair reported an early mortality of 16% and a 10-year survival of 67% (607). SV dysfunction and arrhythmias are the dominant presenting features. Some patients may have symptoms from obstruction of an LV–to–pulmonary artery valved conduit.

12.10.1. Recommendations for Endocarditis Prophylaxis

CLASS IIa

1. Antibiotic prophylaxis before dental procedures that involve manipulation of gingival tissue or the periapical region of teeth or perforation of the oral mucosa is reasonable in those with the following indications:
   a. Prosthetic cardiac valve. (*Level of Evidence: B*)
   b. Previous IE. (*Level of Evidence: B*)
   c. Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: B*)
   d. Completely repaired CHD with prosthetic materials, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure. (*Level of Evidence: B*)
   e. Repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device that inhibit endothelialization. (*Level of Evidence: B*)
2. It is reasonable to consider antibiotic prophylaxis against IE before vaginal delivery at the time of membrane rupture in select patients with the highest risk of adverse outcomes. This includes patients with the following indications:
   a. Prosthetic cardiac valve or prosthetic material used for cardiac valve repair. (*Level of Evidence: C*)
   b. Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: C*)

CLASS III

1. Prophylaxis against IE is not recommended for nondental procedures (such as esophagogastroduodenoscopy or colonoscopy) in the absence of active infection. (*Level of Evidence: C*)

12.10.2. Recommendation for Reproduction

CLASS I

1. **All women with CCTGA (whether repaired or not) should seek counseling from a cardiologist with expertise in ACHD before proceeding with a pregnancy. (*Level of Evidence: C*)**

Pregnancy counseling must be given by physicians with expertise in ACHD who are familiar with the hemodynamic changes of pregnancy. The volume load of pregnancy may pose too great a burden for a compromised SV, particularly with associated SAVV regurgitation. A careful and comprehensive clinical evaluation should be performed when pregnancy is contemplated. This should include a careful history, clinical examination, ECG, chest x-ray, and an assessment of the hemodynamics, presence or absence of valvular lesions, and ejection fraction. This should be evaluated with echocardiography and/or MRI study. An exercise test is helpful in determining the functional capacity of patients, and in general, it is unlikely pregnancy will be well tolerated if the functional aerobic capacity is less than 75% of predicted.

The outcomes of 60 pregnancies in 22 women have been reported (608). There were 50 live births (83%), with a miscarriage rate of 16%. None of the offspring had CHD. Only 1 patient developed heart failure in the third trimester of pregnancy related to SAVV regurgitation. She required SAVV replacement 2 months after delivery. One of the patients in this series had 12 pregnancies and was still alive at 80 years of age. In general, patients with an SV ejection fraction less than 40% and more than mild SAVV regurgitation are unlikely to have a successful pregnancy. Similar results were reported in a smaller series by Therrien et al (609) with a 60% live birth rate. One cyanotic patient developed increasing cyanosis, and 1 patient had a stroke.

12.10.3. Activity

Exercise guidelines should be based on those provided in the 36th Bethesda Conference (Task Force 2 on CHD) (49). In general, modest aerobic activity and maintenance of cardiovascular fitness should be encouraged, but anaerobic exercise should be avoided.

13. Ebstein's Anomaly

13.1. Definition

Ebstein's anomaly is a rare congenital malformation that accounts for approximately 1% of all congenital defects (610–612). It encompasses a wide spectrum of anatomic and functional abnormalities of the morphological tricuspid valve and right ventricle.

13.2. Clinical Course (Unoperated)

The clinical presentation of Ebstein's anomaly depends on the extent of tricuspid valve leaflet distortion, the size of the right side of the heart, the presence/degree of valvular PS, right atrial pressure, the degree of TR, and the presence or absence of right-to-left shunt. The age at presentation depends on the degree of anatomic and hemodynamic derangements. Adults with Ebstein's anomaly should be followed up at centers with expertise in the care of ACHD and Ebstein's anomaly.

13.2.1. Pediatric Presentation

Neonates with Ebstein's anomaly may present with cardiomegaly, congestive heart failure, and cyanosis. Some will improve spontaneously, because PVR normally falls during the first week of life; however, 20% to 40% of all neonates diagnosed with Ebstein's anomaly will not survive 1 month, and fewer than 50% will survive to 5 years of age (613,614). The younger the age at presentation, the more likely it is that a hemodynamic problem exists. Predictors of poor outcome in children and adults are New York Heart Association functional class III or IV symptoms, a cardiothoracic ratio greater than 65%, or atrial fibrillation. Symptomatic children with Ebstein's anomaly may have progressive right-sided heart failure, but most will reach adolescence and adulthood.

13.2.2. Initial Adult Presentation

Patients with mild Ebstein's anomaly may be asymptomatic with no functional limitation. Survival to the ninth decade has been reported (615). Electrophysiological rather than hemodynamic symptoms are more common in patients over the age of 10 years at presentation. Patients with Ebstein's anomaly who reach late adolescence and adulthood often have an excellent outcome (616).

When Ebstein's anomaly presents in adults, the most common symptoms include exercise intolerance with dyspnea, fatigue, symptomatic arrhythmias, and right-sided heart failure. When an ASD or PFO is present, patients may be cyanotic to a varying degree, particularly with exercise. These patients are also at risk for a paradoxical embolism that results in transient ischemic attack, stroke, or cerebral abscess. Occasionally, a significant left-to-right shunt may occur (616). Exercise tolerance declines with age and lower oxygen saturation at rest (617).

End-stage disease with severe TR and ventricular dysfunction may manifest as right-sided and less commonly left-sided heart failure. It may be precipitated by an arrhythmia such as atrial fibrillation. Sudden cardiac death may occur and has been attributed to atrial fibrillation with accelerated conduction through an accessory pathway or from ventricular arrhythmias.

13.3. Clinical Features and Evaluation of the Unoperated Patient

The disorder has the following features in common:

- Adherence of the tricuspid valve leaflets to the underlying myocardium (failure of delamination)
- Apical displacement of the septal and posterior leaflets of the tricuspid valve below the AV junction in the right ventricle
- Atrialization and dilation of the inflow of the right ventricle to varying degrees
- Redundancy, tethering, and fenestrations of the anterior tricuspid valve leaflet
- Varying degrees of TR
- Enlargement of the right atrium
- Varying degrees of cyanosis.

Associated lesions include the following:

- More than 50% of patients have a shunt at the atrial level with either a PFO or secundum ASD, which results in varying degrees of cyanosis
- One or more accessory conduction pathways, increasing the risk of atrial tachycardias (approximately 25%)
- VSD
- Varying degrees of anatomic and physiological RVOT obstruction
- Occasionally, other anomalies such as mitral valve prolapse
- Abnormalities of LV morphology and function.

13.4. Recommendation for Evaluation of Patients With Ebstein's Anomaly

CLASS I

1. **All patients with Ebstein's anomaly should have periodic evaluation in a center with expertise in ACHD. (*Level of Evidence: C*)**

13.4.1. Clinical Examination

Patients with mild Ebstein's anomaly may demonstrate minimal findings on physical examination other than a murmur. The jugular venous pressure is often normal even in the presence of severe TR because of the large and compliant right atrium, which accepts all the regurgitant flow with minimal pressure rise. There may be low cardiac output manifesting as a low pulse volume and peripheral cyanosis. Central cyanosis may be present due to a right-to-left shunt through a PFO or ASD. The RV lift is subtle. On auscultation, the first sound is loud, and there may be 1 or more systolic clicks. The murmur of TR is holosystolic at the lower left sternal border and increases on inspiration. End-stage disease with severe TR and ventricular dysfunction may manifest as right-sided heart failure.

All patients with Ebstein's anomaly should have regular follow-up in a center for congenital cardiology. Unoperated patients need serial monitoring for features that suggest that surgical intervention is required or medical therapy is indicated. An assessment of functional limitation should also be performed.

13.4.2. Electrocardiogram

The ECG is valuable in the diagnosis of Ebstein's anomaly. Preexcitation may be present, usually via a right bypass tract. Multiple bypass tracts may also occur. The P waves are often very tall and peaked (so-called Himalayan P waves). A QR pattern is often seen in lead V_1 and may extend to V_4. QRS duration is usually prolonged, with a right bundle-branch block pattern, but is often "splintered," followed by inverted T waves.

13.4.3. Chest X-Ray

The chest x-ray may be nearly normal in mild cases and in more severe cases shows severe enlargement. Right atrial enlargement is prominent, with a "globular" cardiac contour and clear lung fields. The great arteries are usually small, and the aortic root is inconspicuous or absent.

13.4.4. Echocardiography

The diagnosis of Ebstein's anomaly is most commonly confirmed by TTE Doppler evaluation by a skilled echocardiographer, preferably with expertise in CHD. Echocardiography is the diagnostic test of choice and should document the severity of the degree of right-sided cardiac enlargement, RV dysfunction, and TR. This should also determine whether the tricuspid valve has features that may allow it to be repaired. The atrial septum should be evaluated for the presence of ASD or PFO. Additional associated lesions should also be sought. An assessment of LV function and other cardiac valves should be performed.

TTE supplemented with intraoperative TEE usually provides sufficient data to permit operative intervention without the need to obtain additional preoperative diagnostic structural information in patients with Ebstein's anomaly (618–620). The diagnostic workup may require TEE to assess the presence of an ASD or to delineate intracardiac anatomy in patients with suboptimal TTE images.

13.4.5. Magnetic Resonance Imaging/Computed Tomography

There is increasing interest in the use of MRI and CT in the evaluation of patients with CHD; however, limited information is available on preoperative assessment by these modalities in Ebstein's anomaly. MRI may supply important preoperative information on cardiac structure and function in the future (621–623).

13.5. Recommendations for Diagnostic Tests

CLASS I

1. **ECG, chest x-ray, and echocardiography-Doppler are recommended for the diagnostic evaluation of Ebstein's anomaly in adult patients. (*Level of Evidence: C*)**

CLASS IIa

1. **Pulse oximetry at rest and/or during exercise can be useful in the diagnostic evaluation of Ebstein's anomaly in adult patients. (*Level of Evidence: C*)**
2. **An electrophysiological study can be useful in the diagnostic evaluation of Ebstein's anomaly in adult patients if a supraventricular arrhythmia is documented or suspected (subsequent radiofrequency catheter ablation should be considered if clinically feasible). (*Level of Evidence: C*)**
3. **The following additional diagnostic tests can be useful for the comprehensive evaluation of Ebstein's anomaly in adult patients:**
   a. **Doppler TEE examination if the anatomic information is not provided by transthoracic imaging. (*Level of Evidence: B*)**
   b. **Holter monitoring. (*Level of Evidence: B*)**
   c. **Electrophysiological study for history or ECG evidence of accessory pathway(s). (*Level of Evidence: B*)**
   d. **Coronary angiography when surgical repair is planned, if there is a suspicion of coronary artery disease, and in men 35 years or older, premenopausal women 35 years or older who have coronary risk factors, and postmenopausal women. (*Level of Evidence: B*)**

13.5.1. Cardiac Catheterization

Hemodynamic cardiac catheterization is rarely required in patients with Ebstein's anomaly before surgical intervention is considered. In select high-risk patients, hemodynamic assessment by cardiac catheterization may be helpful for risk stratification. Coronary angiography should be performed before surgical intervention if there is a concern about coronary artery disease.

13.5.2. Problems and Pitfalls

Cardiac disorders that cause TR and right-sided cardiac chamber enlargement may be misdiagnosed as Ebstein's anomaly. Experienced echocardiographic assessment allows differentiation between these entities. Ebstein's anomaly is characterized by apical displacement of the septal tricuspid leaflet of more than 8 mm per m^2 and the presence of a redundant, elongated anterior tricuspid leaflet. Misdiagnoses include tricuspid valve dysplasia, tricuspid valve prolapse, traumatic changes of the tricuspid valve, arrhythmogenic RV cardiomyopathy, tricuspid valve endocarditis, and carcinoid heart disease (624). The severity of the TR may be underestimated because of the subtle physical findings and the laminar tricuspid regurgitant flow on echocardiography.

13.6. Management Strategies

13.6.1. Recommendation for Medical Therapy

CLASS I

1. **Anticoagulation with warfarin is recommended for patients with Ebstein's anomaly with a history of paradoxical embolus or atrial fibrillation. (*Level of Evidence: C*)**

Patients with mild forms of Ebstein's anomaly may be followed up medically for many years. Regular evaluation by a cardiologist with expertise in CHD is recommended. Particular attention should be given to the patient's rhythm status because of the high incidence of supraventricular arrhythmia, which may require antiarrhythmic therapy or electrophysiological intervention. Exercise testing facilitates a more reliable assessment of functional capacity, because many patients may believe themselves to be asymptomatic. Progressive RV enlargement, RV dysfunction, and progressive TR should prompt consideration of surgical intervention, particularly if the patient is cyanotic. The onset of peripheral edema in this situation usually reflects advanced RV dysfunction. Diuretics may result in reduction of peripheral edema in Ebstein patients with right-sided heart failure but will not affect the fatigue and dyspnea related to low left-sided cardiac output.

13.6.2. Physical Activity

Recommendations are summarized in the Task Force 1 report on CHD (274). Adults with mild Ebstein's anomaly, nearly normal heart size, and no arrhythmias can participate in all sports. Athletes with severe Ebstein's anomaly are precluded from sports unless the patient has undergone optimal repair with the heart size being nearly normal and there is no history of arrhythmias.

13.7. Recommendation for Catheter Interventions for Adults With Ebstein's Anomaly

CLASS I

1. **Adults with Ebstein's anomaly should have catheterization performed at centers with expertise in catheterization and management of such patients. (*Level of Evidence: C*)**

Few data are available regarding catheterization of the adult with Ebstein's anomaly. The adult with unrepaired Ebstein's anomaly may demonstrate a variable degree of shunt-related cyanosis due to the combination of TR, RV dysfunction, and a PFO or ASD. Rarely, in those with TR not severe enough to warrant surgical repair, closure of the atrium-level shunt may reduce cyanosis and improve functional capacity sufficiently to outweigh the theoretical risk to RV function posed by removing the "pop-off" from the RV and increasing its afterload. Few data are available regarding transcatheter ASD closure in this setting.

13.7.1. Recommendation for Electrophysiology Testing/Pacing Issues in Ebstein's Anomaly

CLASS IIa

1. **Catheter ablation can be beneficial for treatment of recurrent supraventricular tachycardia in some patients with Ebstein's anomaly. (*Level of Evidence: B*)**

Supraventricular tachycardia related to accessory pathways is a frequent accompaniment of Ebstein's anomaly (625). Catheter ablation has become the most attractive treatment for this condition, although the procedure can be quite challenging. Overall, success rates are lower and recurrence rates higher than those reported for ablation in a structurally normal heart (141,143), in part because multiple accessory pathways are present in nearly 50% of these patients (626). Any patient suspected of having an accessory pathway should undergo electrophysiology study before surgical repair, so that the accessory pathway(s) may be localized and catheter ablation attempted. If catheter ablation is unsuccessful or deemed inappropriate for any reason, surgical interruption can be performed in the operating room. For any patients with history of atrial flutter, a right atrial Maze procedure can be incorporated into the surgery, and for those with atrial fibrillation, a biatrial Maze can be performed.

13.7.2. Recommendations for Surgical Interventions

CLASS I

1. **Surgeons with training and expertise in CHD should perform tricuspid valve repair or replacement, with concomitant closure of an ASD, when present, for patients with Ebstein's anomaly with the following indications:**
   a. **Symptoms or deteriorating exercise capacity. (*Level of Evidence: B*)**
   b. **Cyanosis (oxygen saturation less than 90%). (*Level of Evidence: B*)**
   c. **Paradoxical embolism. (*Level of Evidence: B*)**
   d. **Progressive cardiomegaly on chest x-ray. (*Level of Evidence: B*)**

e. Progressive RV dilation or reduction of RV systolic function. (*Level of Evidence: B*)

2. Surgeons with training and expertise in CHD should perform concomitant arrhythmia surgery in patients with Ebstein's anomaly and the following indications:
   a. Appearance/progression of atrial and/or ventricular arrhythmias not amenable to percutaneous treatment. (*Level of Evidence: B*)
   b. Ventricular preexcitation not successfully treated in the electrophysiology laboratory. (*Level of Evidence: B*)
3. Surgical rerepair or replacement of the tricuspid valve is recommended in adults with Ebstein's anomaly with the following indications:
   a. Symptoms, deteriorating exercise capacity, or New York Heart Association functional class III or IV. (*Level of Evidence: B*)
   b. Severe TR after repair with progressive RV dilation, reduction of RV systolic function, or appearance/progression of atrial and/or ventricular arrhythmias. (*Level of Evidence: B*)
   c. Bioprosthetic tricuspid valve dysfunction with significant mixed regurgitation and stenosis. (*Level of Evidence: B*)
   d. Predominant bioprosthetic valve stenosis (mean gradient greater than 12 to 15 mm Hg). (*Level of Evidence: B*)
   e. Operation can be considered earlier with lesser degrees of bioprosthetic stenosis with symptoms or decreased exercise tolerance. (*Level of Evidence: B*)

The primary operation generally consists of closure of any interatrial communications; antiarrhythmia procedures such as surgical division of accessory conduction pathways, cryoablation of AV node reentry tachycardia, or Maze procedure; and tricuspid valve surgery. The tricuspid valve is repaired when feasible, and tricuspid valve replacement is performed with a mechanical or heterograft bioprosthesis when repair is not feasible or the repair result is not satisfactory. A right reduction atrioplasty is often performed.

A bidirectional cavopulmonary anastomosis is considered in selected patients with severe RV dysfunction and preserved LV function with low left atrial pressure. The single-ventricular–Fontan pathway may be considered for profound RV dysfunction most often when operation is required during infancy. Heart transplantation is considered when significant LV dysfunction has occurred (ejection fraction less than 30%) and important symptoms of heart failure are present.

Reoperation usually requires tricuspid valve replacement or rereplacement (tissue or mechanical). Rerepair of the tricuspid valve is rarely successful. Other procedures are performed as with the primary operation. A concomitant Maze procedure may be performed for intermittent or chronic atrial fibrillation/flutter. Congenital heart surgeons should perform operations for patients with Ebstein's anomaly. The management of patients should be in tertiary CHD centers or children's hospitals with experienced medical and surgical personnel.

13.7.3. Postoperative Findings

Operated patients with Ebstein's anomaly require lifelong specialized surveillance for recurrent native tricuspid valve dysfunction after repair, prosthetic valve degeneration after replacement, atrial and ventricular arrhythmias, and ventricular dysfunction (627). Postoperative exercise tolerance is generally significantly improved compared with preoperative exercise tolerance, especially in patients with an ASD. Age, gender, and heart size influence postoperative exercise tolerance (628).

13.7.4. Expected Postoperative Course

Early mortality is approximately 5% to 10% in experienced centers. Late survival is favorable and is 92% at 10 years postoperatively. Late survival after reoperation for recurrent TR or bioprosthetic deterioration is similar (80% at 15 years). Tricuspid valve replacement can be associated with a high incidence of complete AV block, especially in centers with less experience.

13.8. Problems and Pitfalls

The problems and pitfalls associated with the management of adults with Ebstein's anomaly are as follows:

- Patients with Ebstein's anomaly may be referred for percutaneous or surgical ASD closure; however, the presence of Ebstein's anomaly may alter the recommendation for intervention.
- Percutaneous ablation of an accessory pathway should be performed with caution in patients with Ebstein's anomaly and an interatrial communication with right-to-left shunt because of the risk of paradoxical embolus.
- The presence of multiple accessory pathways should raise the suspicion for Ebstein's anomaly.
- Patients with Ebstein's anomaly and marked cardiomegaly may complain of few symptoms despite marked limitation. Exercise testing will demonstrate functional limitation and should be included as part of the regular assessment of these patients. Exercise testing should include monitoring of oxygen saturation, because exercise-induced cyanosis may occur.
- Patients with newly diagnosed Ebstein's anomaly may be told they have concomitant PAH, particularly when cyanosis and right-sided heart enlargement are present. This is usually a misdiagnosis, because PAH is very rare among Ebstein patients.
- Other tricuspid valve disorders may be misdiagnosed as Ebstein's anomaly (refer to Section 13.5.2, Problems and Pitfalls).

13.9. Recommendation for Reproduction

CLASS I

1. Women with Ebstein's anomaly should undertake prepregnancy counseling with a physician with expertise in ACHD. (*Level of Evidence: C*)

Most women with Ebstein's anomaly can have a successful pregnancy with proper care, but there is an increased risk of low birth weight and fetal loss if significant cyanosis is present. The risk of CHD in the offspring (in the absence of a family history) is approximately 6% (629).

13.10. Recommendation for Endocarditis Prophylaxis

CLASS IIa

1. **Antibiotic prophylaxis before dental procedures that involve manipulation of gingival tissue or the periapical region of the teeth or perforation of the oral mucosa is reasonable in cyanotic patients with Ebstein's anomaly and postoperative patients with a prosthetic cardiac valve. (*Level of Evidence: C*)**

Antibiotic prophylaxis is usually unnecessary in the acyanotic unoperated patient (refer to Section 1.6, Recommendations for Infective Endocarditis, for additional information).

14. Tricuspid Atresia/Single Ventricle

14.1. Definition

This section will focus on conditions that are not amenable to biventricular repair and will include the various types of so-called univentricular hearts, such as tricuspid atresia, mitral atresia, double-inlet left ventricle, single ventricle, hypoplastic right ventricle or left ventricle, and heterotaxia syndromes. The scope of these guidelines does not allow detailed anatomic descriptions of all of these conditions, but excellent descriptions can be found elsewhere (630).

Some associated lesions include:

- BAV, valvular AS or SubAS, valvular PS or subvalvular PS, pulmonary atresia
- Coarctation, interrupted aortic arch
- VSD, ASD, PDA, AV septal defect
- Ventricular outflow obstruction secondary to small VSD in tricuspid atresia with TGA, bulboventricular foramen narrowed in single ventricle
- AV valve stenosis; regurgitation; overriding, straddling valves
- Pulmonary artery stenosis, hypoplasia, absence on 1 side
- Partial or total anomalous pulmonary venous connection
- Absent infrahepatic inferior vena cava with azygous or hemiazygous connection
- Left superior vena cava, absent innominate vein, absent right superior vena cava, superior vena cava or inferior vena cava connection to the left atrium
- Left superior vena cava to coronary sinus (unroofed) with right-to-left shunt
- Stenotic or atretic orifice of coronary sinus
- Polysplenia or asplenia.

14.2. Clinical Course (Unoperated and Palliated)

Patients usually fall into 2 general categories. The first category includes those patients with no anatomic restrictions to pulmonary blood flow with early postnatal development of a large left-to-right shunt and symptoms of congestive heart failure. This condition may be exacerbated by obstructions to systemic blood flow due to hypoplasia of the aortic arch, including coarctation of the aorta with or without obstruction at the VSD or bulboventricular foramen in patients with double-inlet left ventricle or tricuspid atresia with TGA. Such patients may survive into adulthood with pulmonary vascular disease (refer to Section 9, Pulmonary Hypertension/Eisenmenger physiology). Surgical treatment is usually needed early in life to decrease any systemic outflow obstruction and decrease pulmonary flow and pressure. Coarctation repair and pulmonary artery banding are operations frequently performed in infancy for this patient group.

The second major clinical presentation is severe cyanosis due to obstruction to pulmonary flow, frequently caused by valvular or subvalvular PS or atresia. These patients usually undergo a systemic–to–pulmonary artery shunt procedure, such as a modified Blalock-Taussig shunt, early in infancy to augment pulmonary flow. A small number of patients, usually with the right-isomerism type of heterotaxia, can also have total anomalous pulmonary venous connection, which can be obstructed. These patients usually require repair of the total anomalous pulmonary venous connection at the time of placement of a systemic arterial shunt.

A small number of patients will present with mild cyanosis and no congestive heart failure. These patients have sufficient PS to limit pulmonary flow to levels that do not cause heart failure symptoms but is adequate to prevent severe hypoxemia. The vast majority of adults with these conditions will have undergone previous palliation with some type of systemic–to–pulmonary artery shunt, cavopulmonary connection (bidirectional Glenn), or 1 of the modifications of the Fontan operation (631,632).

14.3. Clinical Features and Evaluation of the Unoperated or Palliated Patient

14.3.1. Presentation

Those with no prior operation or with only a systemic–to–pulmonary artery shunt or cavopulmonary shunt can present with cyanosis, congestive heart failure, arrhythmia, complete AV block, stroke, worsening exercise ability, bacterial endocarditis, or thromboembolism, or they may seek a physician's advice because of pregnancy.

14.3.2. Clinical Examination

Patients who have not had a Fontan operation usually will have cyanosis, clubbing, increased precordial activity, and a single S_2. Possible murmurs include continuous murmurs of aorticopulmonary shunts, systolic murmurs of AV valve regurgitation, systolic murmurs of LV or RV outflow obstruction, and diastolic murmurs of semilunar valve regurgitation. Those with ventricular dysfunction may have an S_3, jugular venous distention, and hepatomegaly. Brachial pulses may be absent on the side of a prior Blalock-Taussig shunt and in the left arm after a subclavian flap procedure for coarctation. Scoliosis is common.

14.3.3. Electrocardiogram

The ECG is useful to detect rhythm disturbances. Any patient with unexplained tachycardia may have IART (also called slow atrial flutter). Fixed ventricular rates of 90 to 120 beats per minute are common in IART with 2:1 AV conduction and only 1 P wave visible, with the second P wave buried in the QRS or T wave. Patients with right or left atrial enlargement

or prior atrial surgical incisions/sutures are most at risk for this complication.

Right or left atrial enlargement is common, as is RV hypertrophy, LV hypertrophy (depending on the morphology of the underlying single ventricle), and biventricular hypertrophy patterns. Increased QRS voltage, an RS pattern in all precordial leads, abnormal septal depolarization with no Q in V_6, and intraventricular conduction delays are common variants.

14.3.4. Chest X-Ray

Cardiac enlargement on chest x-ray correlates with significant RV or LV enlargement in the absence of pericardial effusion. Dextrocardia or mesocardia is common. Pulmonary vascularity is variable. Scoliosis is common; rib abnormalities are also common on the side of a prior thoracotomy.

14.3.5. Echocardiography

Echocardiography is the major imaging modality. Listed below are the data to be obtained with a complete echocardiographic assessment of adults with tricuspid atresia/single ventricle:

- Abdominal/atrial situs
- Cardiac apex position, AV and ventriculoarterial connections, ventricular and arterial looping
- Systemic venous and pulmonary venous anatomy and flow patterns
- Right-to-left shunt and left-to-right shunt pathways
- Valvular abnormalities/outflow obstruction
- ASD/VSD size, numbers, and location
- Ventricular function/hypertrophy
- Aortic/pulmonary artery abnormalities, including coarctation, pulmonary artery size, and the presence or absence of stenosis.

TEE may be needed if all information is not available from TTE, historical data, or other imaging modalities.

14.3.6. Magnetic Resonance Imaging/ Computed Tomography

These modalities can be extremely useful for imaging systemic and pulmonary arterial and venous anatomy and intracardiac complex anatomy and for determining ventricular volumes, ejection fraction, regurgitant fraction, and degree of hypertrophy. MRI or CT data can obviate the need for catheterization imaging in many situations, as well as prepare the cardiologist/interventionalist for the catheterization in an optimal manner.

14.3.7. Recommendation for Catheterization Before Fontan Procedure

CLASS I

1. In the evaluation of hemodynamics to assess the potential for definitive palliation of unoperated or shunt-palliated adults with univentricular hearts, catheterization is indicated to:

a. Assess the nature of pulmonary artery obstruction, with potential to restore maximal continuous, effective, unimpeded systemic venous flow to the maximal number of pulmonary artery segments. (*Level of Evidence: C*)

b. Assess and eliminate systemic–to–pulmonary vein collaterals. (*Level of Evidence: C*)

c. Assess and eliminate systemic–to–pulmonary artery connections. (*Level of Evidence: C*)

d. For adults with systemic-to-pulmonary shunts, the potential for perioperative transcatheter shunt exclusion should be examined. (*Level of Evidence: C*)

This would include patients previously palliated with a systemic-to-pulmonary shunt and the rare patient who has not had prior operation. Data to be obtained include intracardiac, pulmonary artery, and aortic pressures; oxygen saturations; and estimations of pulmonary and systemic blood flow and resistances. Imaging data would include angiograms of systemic venous anatomy, great vessel anatomy (specifically, anatomy of the pulmonary arteries and estimations of ventricular volume), hypertrophy, and ejection fraction. Coronary angiography is needed for older patients and those with questionable ischemia or coronary anomalies. Assessment of venous and arterial pulmonary collaterals is also important, because these may be amenable to coil occlusion.

14.4. Recommendation for Surgical Options for Patients With Single Ventricle

CLASS I

1. Surgeons with training and expertise in CHD should perform operations for single-ventricle anatomy or physiology. (*Level of Evidence: C*)

Surgical options for the treatment of adults with tricuspid atresia/single ventricle are outlined below.
Systemic–to–pulmonary artery shunt:

- Often from the ascending aorta to the main or right pulmonary artery; rarely performed as an isolated procedure, and only if a cavopulmonary connection is contraindicated.

Bidirectional Glenn (bidirectional cavopulmonary anastomosis [BDCPA]):

- Most commonly performed in infancy or early childhood as a staged procedure toward the Fontan completion; this provides a stable source of pulmonary blood flow without volume loading the SV; it generally should not be the sole source of pulmonary blood flow (except as the stage II procedure for hypoplastic left-sided heart syndrome).

BDCPA plus additional pulmonary blood flow:

- The most reliable source of additional pulmonary blood flow is via the native RVOT with native PS or with a pulmonary artery band. A concomitant systemic–to–pulmonary artery shunt may be added if an increase in systemic oxygenation is required, but this is at the expense of an increase in volume load on the SV and often elevated superior vena cava pressure.

Single-ventricle repair:

Table 17. Late Outcome Results After Repair of Tricuspid Atresia/Single-Ventricle Disease

Intervention	Survival Rate	Complications
Systemic-PA shunt	50% at 20 years	Systemic ventricular dilatation and failure; atrial fibrillation/flutter
BDCPA	50% at 20 years	Progressive cyanosis may occur because of relatively greater IVC flow vs SVC flow or from the development of pulmonary arteriovenous fistulas
BDCPA plus additional pulmonary blood flow	N/A	Volume loading of the systemic ventricle occurs with systemic-to-PA shunt
Fontan palliation	Approximately 90% at 10 years in the absence of risk factors; 80% at 10 years for all patients	Late complications include atrial arrhythmias, thrombus formation, PLE, progressive systemic ventricular failure, progressive AV valve regurgitation
1.5-Ventricle repair	N/A	N/A
2-Ventricle repair	N/A	Results may be inferior to a simple 1- or 1.5-ventricle repair if the 2-ventricle repair requires complex intraventricular tunnel closure of VSD or an extracardiac conduit or AV valve replacement
Heart transplantation	85% to 90% at 3 years, 50% to 70% at 10 years	Side effects of immunosuppression; lymphomas
Heart-lung transplantation	65% at 1 year; 50% at 5 years	Bronchiolitis obliterans

PA indicates pulmonary artery; BDCPA, bidirectional cavopulmonary anastomosis; IVC, inferior vena cava; SVC, superior vena cava; N/A, not available; PLE, protein-losing enteropathy; AV, atrioventricular; and VSD, ventricular septal defect.

- When the rudimentary pulmonary ventricle is less than 30% of its normal volume, a Fontan type of operation is performed. The operation has gone through many modifications; each allows systemic venous return to enter the pulmonary circulation directly.

Modified Fontan procedures:

- Extracardiac conduit–BDCPA plus conduit from inferior vena cava to right pulmonary artery/main pulmonary artery
- Intra-atrial conduit–BDCPA plus intra-atrial conduit from inferior vena cava to right pulmonary artery/main pulmonary artery; preferred when the ventricular mass would lie on top of an extracardiac conduit, eg, isolated dextrocardia or isolated levocardia with situs inversus
- Intracardiac lateral tunnel plus BDCPA
- Intracardiac lateral tunnel
- Atriopulmonary connection (rarely used in the current era)
- Fenestration between systemic venous pathway and left atrium.

1.5-Ventricle repair:

A term used to describe a procedure for cyanotic CHD performed when the pulmonary ventricle is insufficiently developed to accept the entire systemic venous return. A BDCPA is constructed to direct superior vena cava blood directly into the pulmonary arteries while the inferior caval blood is directed to the lungs via the small pulmonary ventricle.

2-Ventricle repair:

A term used to describe a procedure for cyanotic CHD with a common ventricle or adequately sized pulmonary ventricles and SVs that communicate via a VSD. The pulmonary and systemic circulations are surgically septated by placement of an interventricular patch (for common ventricle) or VSD patch (for separate pulmonary and SV cavities).

Transplantation:

- Heart transplantation and heart/lung transplantation are reserved for severe SV failure with or without PAH when there is no conventional surgical option.

The Fontan operation is a palliative procedure for patients with a functional or anatomic single ventricle or complex anomaly considered unsuitable for a biventricular repair. The systemic venous return is directed to the pulmonary artery, usually without use of a subpulmonary ventricle. The original classic Glenn anastomosis followed by direct atriopulmonary connection is seldom performed today. Many adult patients currently seen in congenital heart clinics, however, have had a direct atriopulmonary connection from either the right atrium or atrial appendage to the pulmonary arteries. Such patients are particularly vulnerable to right atrial dilation, atrial arrhythmias, and thrombus formation. These operations have been largely replaced by a BDCPA followed by a lateral tunnel or extracardiac conduit (633–635). A fenestration between the systemic venous pathway and left atrium may be added at the time of the primary Fontan procedure or Fontan conversion or after the Fontan procedure when PLE has developed. Late outcome results are summarized in Table 17.

14.5. Recommendation for Evaluation and Follow-Up After Fontan Procedure

CLASS I

1. Lifelong follow-up is recommended for patients after a Fontan type of operation; this should include a yearly evaluation by a cardiologist with expertise in the care of ACHD patients. (*Level of Evidence: C*)

All patients should have follow-up with a cardiologist who has expertise in ACHD. The frequency, although typically

annual, may be determined by the extent and degree of residual abnormalities. Long-term problems include atrial arrhythmias and right atrial thrombus, especially common in direct atrium–to–pulmonary artery connections; ventricular dysfunction and edema; need for reoperation; hepatic congestion and dysfunction; and PLE.

Ten-year survival after a Fontan operation is 90%, depending on the number of risk factors present at the time of the initial Fontan procedure (634). If PLE develops, the 5-year survival is decreased to approximately 50%. The usual causes of late death are those related to SV failure, arrhythmias, reoperation, and PLE.

14.6. Clinical Features and Evaluation

14.6.1. Clinical Examination

After a successful Fontan operation, most patients have no murmurs, and the second sound is single. Mild jugular venous distention (usually nonpulsatile) is common after Fontan procedures, even in the absence of congestive heart failure. Significant jugular venous distension and hepatomegaly should raise the suspicion of Fontan obstruction. Such patients frequently will have mild cyanosis that is accentuated with any aerobic activity. In the presence of a prior Glenn procedure, jugular venous pressure will not reflect right atrial pressure, and Fontan obstruction may be overlooked.

14.6.2. Electrocardiogram

The ECG has the same features as in the unoperated patient, although atrial arrhythmias are even more likely to occur in the postoperative patient.

14.6.3. Chest X-Ray

The chest x-ray should show normal heart size if the hemodynamics are satisfactory, and pulmonary vascularity should be normal. If pleural effusions are present, this indicates the need for a workup for hemodynamic abnormalities or PLE (636).

14.6.4. Recommendation for Imaging

CLASS I

1. All patients with prior Fontan type of repair should have periodic echocardiographic and/or magnetic resonance examinations performed by staff with expertise in ACHD. (*Level of Evidence: C*)

Echocardiography is the cornerstone of the postoperative evaluation, and a comprehensive examination as outlined previously (refer to Section 14.3.5, Echocardiography) is necessary. Spontaneous contrast is often seen in the Fontan circuit and represents slow flow in the pathway. It is important, however, to image the Fontan pathway in its entirety, and TEE is often necessary to accomplish this. In addition, TEE is needed to rule out right atrial thrombus. The presence or absence of a Fontan fenestration should be sought, and if present, gradient across the fenestration should be measured.

14.7. Recommendation for Diagnostic and Interventional Catheterization After Fontan Procedure

CLASS I

1. Catheterization of adults with a Fontan type of repair of single-ventricle physiology should be performed in regional centers with expertise in ACHD. (*Level of Evidence: C*)

For adults after Fontan palliation, cardiac catheterization, often assisted by contrast echocardiography, is indicated to investigate and potentially treat unexplained volume retention, fatigue or exercise limitation, atrial arrhythmia, or cyanosis and hemoptysis. To further investigate volume retention or fatigue in the adult Fontan survivor, catheterization is directed at assessment of systemic AV valve regurgitation, ventricular dysfunction (both systolic and diastolic), cardiac output, pulmonary artery anatomy (including the branch pulmonary arteries), and pulmonary resistance. Any degree of obstruction in the nonpulsatile Fontan circuit is important. Systemic arterial–to–pulmonary venous or systemic arterial–to–pulmonary arterial connections may be defined and occluded if necessary. On unusual occasions, the Fontan pathway pressure may be sufficiently high and without potential for relief to warrant the creation of a Fontan baffle fenestration.

To further investigate oxygen-unresponsive hypoxemia in the adult Fontan survivor, catheterization is directed at assessing and potentially relieving (when applicable) the following: persistent Fontan fenestration; systemic venous–to–pulmonary venous collaterals; pulmonary arteriovenous malformations; and the cause of volume retention, increasing Fontan pathway pressure and resistance, and thereby worsening right-to-left shunting.

Evaluation of postoperative Fontan patients with worsening cyanosis (oxygen saturation usually 90% or less at rest and decreasing with exercise):

In addition to pressure and resistance data, an angiographic search for atrial right-to-left shunts and shunts from the inferior cava, superior cava, and innominate vein to the left atrium should be performed, as well as a search for pulmonary arteriovenous malformations. Interventional closure of residual shunts by coils or ASD devices is often possible.

14.7.1. Evaluation of Patients With Protein-Losing Enteropathy

In addition to pressure and resistance data, an angiographic search for any obstruction to pulmonary flow, such as pulmonary artery or venous stenosis or AV valve stenosis or regurgitation, should be performed. Aortography should also be performed to determine whether prominent aortic-pulmonary collateral vessels are causing increased resistance to effective pulmonary flow. Creation or enlargement of an ASD may be needed to decrease central venous pressure.

To evaluate patients with elevated pulmonary artery pressure for pulmonary artery modulating therapies or transplantation:

In addition to obtaining pressure and resistance data before and after acute vasodilator testing, imaging of systemic and

pulmonary arteries and venous anatomy is essential to determine potential problems and suggest the need for innovative surgical techniques that would be required for transplant surgery.

14.7.2. Problems and Pitfalls

The major problems and pitfalls in the management of adults after a Fontan procedure are listed below (375,637):

- Worsening cyanosis caused by new right-to-left shunts or pulmonary arteriovenous fistulas, most frequently seen after cavopulmonary connection
- Unrecognized arrhythmia: atrial reentry tachycardia with 2:1 block and modest tachycardia (rates frequently less than 150 beats per minute)
- Unrecognized outflow obstruction at the bulboventricular foramen or VSD with tricuspid atresia and d-TGA
- Edema due to unrecognized PLE
- PLE associated with small gradients in the Fontan circuit
- Attempts at central line or Swan placement by physicians unfamiliar with the patient's complex venous anatomy
- Right pulmonary vein obstruction by enlarged right atrium in patients with right atrium–to–pulmonary artery Fontan connection
- Need for meticulous intravenous line care to avoid air embolism to systemic circulation in those with a residual right-to-left shunt
- Falsely low blood pressure recorded in extremity with prior Blalock-Taussig shunt
- Cirrhosis in post-Fontan patients
- The combination of hepatic distension and jugular venous distension raises the possibility of Fontan obstruction
- In the presence of a Glenn shunt, the jugular venous pressure may be normal, and Fontan obstruction may manifest as hepatic distension, and later, peripheral edema
- Ascites, peripheral edema, and pleural effusions should prompt a search for PLE
- The onset of atrial arrhythmias should prompt a search for Fontan obstruction
- Patients with atrial arrhythmias should be given anticoagulation therapy
- Patients with residual ASDs/fenestrations should be given anticoagulation therapy.

14.8. Recommendations for Management Strategies for the Patient With Prior Fontan Repair

CLASS I

1. **Management of patients with prior Fontan repair should be coordinated with a regional ACHD center. Local cardiologists, internists, and family care physicians should develop ongoing relationships with such a center with continuous availability of specialists. (*Level of Evidence: C*)**
2. **At least yearly follow-up is recommended for patients after Fontan repair. (*Level of Evidence: C*)**
3. **Arrhythmia management is frequently an issue, and consultation with an electrophysiologist is recommended as a vital part of care. (*Level of Evidence: C*)**
4. **New-onset atrial tachyarrhythmia should prompt a comprehensive noninvasive imaging evaluation to identify associated atrial/baffle thrombus, anatomic abnormalities of the Fontan pathway, or ventricular dysfunction. (*Level of Evidence: C*)**

14.8.1. Recommendations for Medical Therapy

CLASS I

1. **Warfarin should be given for patients who have a documented atrial shunt, atrial thrombus, atrial arrhythmias, or a thromboembolic event. (*Level of Evidence: C*)**

CLASS IIa

1. **It is reasonable to treat SV dysfunction with ACE inhibitors and diuretics. (*Level of Evidence: C*)**

Ventricular dysfunction, congestive heart failure, symptomatic arrhythmias, thromboembolism, and edema are all possible findings on long-term follow-up and require management directed by an ACHD center as defined in these guidelines. Many patients require afterload reduction with ACE inhibitors. Many adult survivors also require diuretic therapy. Antiarrhythmic drugs may be necessary to control atrial arrhythmias, although caution must be used with dosage, because sinus node dysfunction is common, and if AV block ensues, venous access for pacing may not be possible depending on the Fontan anatomy. Additionally, for those patients with dysfunction of the single ventricle, negative inotropic drugs should be avoided. Anticoagulants should be given to all patients with atrial arrhythmias even if atrial thrombus has not been documented. Warfarin should also be given to those with a residual ASD, especially those with dual atrial pulmonary connections, spontaneous right atrial contrast on echocardiography, and an ejection fraction less than 40%.

Persistent edema, pleural effusions, and/or ascites should prompt a search for PLE. This may be confirmed by documentation of low serum albumin and by the presence of an elevated alpha 1 antitrypsin level in the stool. Medical treatment for PLE is challenging; patients should be managed at an ACHD center and merit consideration for cardiac transplantation.

14.9. Recommendations for Surgery for Adults With Prior Fontan Repair

CLASS I

1. **Surgeons with training and expertise in CHD should perform operations on patients with prior Fontan repair for single-ventricle physiology. (*Level of Evidence: C*)**
2. **Reoperation after Fontan is indicated for the following:**
   a. **Unintended residual ASD that results in right-to-left shunt with symptoms and/or cyanosis not amenable to transcatheter closure. (*Level of Evidence: C*)**
   b. **Hemodynamically significant residual systemic artery–to–pulmonary artery shunt, residual surgical shunt, or residual ventricle–to–pulmonary artery connection not amenable to transcatheter closure. (*Level of Evidence: C*)**
   c. **Moderate to severe systemic AV valve regurgitation. (*Level of Evidence: C*)**
   d. **Significant (greater than 30-mm Hg peak-to-peak) subaortic obstruction. (*Level of Evidence: C*)**
   e. **Fontan pathway obstruction. (*Level of Evidence: C*)**

f. Development of venous collateral channels or pulmonary arteriovenous malformation not amenable to transcatheter management. (*Level of Evidence: C*)
g. Pulmonary venous obstruction. (*Level of Evidence: C*)
h. Rhythm abnormalities, such as complete AV block or sick sinus syndrome, that require epicardial pacemaker insertion. (*Level of Evidence: C*)
i. Creation or closure of a fenestration not amenable to transcatheter intervention. (*Level of Evidence: C*)

CLASS IIa

1. Reoperation for Fontan conversion (ie, revision of an atriopulmonary connection to an intracardiac lateral tunnel, intra-atrial conduit, or extracardiac conduit) can be useful for recurrent atrial fibrillation or flutter without hemodynamically significant anatomic abnormalities. A concomitant Maze procedure should also be performed. (*Level of Evidence: C*)

CLASS IIb

1. Heart transplantation may be beneficial for severe SV dysfunction or PLE. (*Level of Evidence: C*)

Reoperation includes valve repair or replacement for systemic AV valve regurgitation, resection of subaortic obstruction, closure of an unintended residual shunt, revision of Fontan pathway obstruction, or Fontan conversion for atrial tachyarrhythmias with or without anatomic abnormalities (638). Venous collateral channels or arteriovenous malformations in the right lung in the presence of a classic Glenn shunt may be ameliorated by conversion to a modified Fontan procedure. This enables hepatic venous blood to perfuse the right-sided pulmonary vascular bed (631). Arteriovenous malformations often regress, provided they are not large and have not been long standing. Clinically significant persistent venous collateral channels or systemic aortopulmonary collaterals are usually treated with transcatheter occlusion.

Atrial tachycardias can be treated by catheter ablation versus Fontan conversion with Maze procedure (639). Complete AV block or sick sinus syndrome commonly requires permanent pacing, usually epicardial.

PLE not amenable to medical or catheter therapy may be treated by creation of an atrial septal fenestration or Fontan conversion. The Fontan revision carries an operative mortality rate of 5% to 25% in reported series (636,640). If PLE is due to Fontan pathway obstruction, successful revision of the Fontan communication may be curative. PLE often requires heart transplantation (640), although the PLE does not always resolve. Severe SV dysfunction often requires heart transplantation (641).

14.10. Key Issues to Evaluate and Follow-Up

14.10.1. Recommendations for Electrophysiology Testing/Pacing Issues in Single-Ventricle Physiology and After Fontan Procedure

CLASS I

1. Arrhythmia management is frequently an issue in patients after the Fontan procedure, and consultation with an electrophysiologist with expertise in CHD is recommended as a vital part of care. (*Level of Evidence: C*)
2. New-onset atrial tachyarrhythmias should prompt a comprehensive noninvasive imaging evaluation to identify associated atrial/baffle thrombus, anatomic abnormalities of the Fontan pathway, or ventricular dysfunction. (*Level of Evidence: C*)
3. Electrophysiological studies in adults with Fontan physiology should be performed at centers with expertise in the management of such patients. (*Level of Evidence: C*)
4. Clinicians must be mindful of the high risk for symptomatic IART in adult patients who have undergone the Fontan operation. This arrhythmia can cause serious hemodynamic compromise and contribute to atrial thrombus formation. Treatment is often difficult, and consultation with an electrophysiologist who is experienced with CHD is recommended whenever recurrent IART is detected. (*Level of Evidence: C*)

The most significant rhythm issue facing adults who have undergone the Fontan operation is recurrent IART. This arrhythmia is a major source of morbidity in the post-Fontan population, especially for patients who have undergone an atriopulmonary connection and subsequently developed advanced degrees of dilation, thickening, and scarring of their right atrial chamber (642). Newer modifications in the Fontan technique involving cavopulmonary connections have resulted in a more favorable rhythm outcome (634), but there is a large population of patients who underwent repair in the older fashion who remain at risk. More than 50% of patients with atriopulmonary connections will develop IART within 15 years of operation compared with fewer than 10% of patients with lateral tunnel or extracardiac conduit connections. Beyond the surgical technique, other risk factors for development of IART include concomitant sinus node dysfunction and older age at time of Fontan operation (139). Tachycardia episodes can result in significant hemodynamic compromise and, if long in duration, clot formation within the dilated right artery.

The reentrant circuits responsible for IART in post-Fontan patients tend to propagate through regions of fibrotic right atrial muscle located near lateral-wall atriotomy scars, atrial septal patches, or the region of anastomosis with the pulmonary artery (583). Natural conduction barriers, such as the crista terminalis and the superior and inferior vena caval orifices, also influence these circuits (643). Quite often, multiple potential IART circuits can be present in the same patient (147). Once recognized, acute termination of IART can be accomplished with direct current cardioversion, overdrive pacing (644), or certain class I or III antiarrhythmic medications. Prevention of recurrent IART, however, remains a major challenge.

Multiple strategies have evolved to address recurrent IART, all of which have merit in select patients but none of which can be considered a universal solution. Recurrent IART treatment options after the Fontan operation are as follows:

- Elective direct current cardioversion (if IART episodes are very infrequent, recognized promptly, and well tolerated)
- TEE is recommended before direct current cardioversion to rule out atrial thrombus, unless there is clear documenta-

tion the patient has been therapeutically anticoagulated for several weeks
- Implantation of an antibradycardia pacemaker (if significant sinoatrial node dysfunction is present)
- Implantation of an atrial antitachycardia pacemaker
- Antiarrhythmic drugs (assuming good sinoatrial node function and reasonable ventricular function)
- Catheter ablation
- Surgical revision of atriopulmonary connection to lateral tunnel or extracardiac conduit, combined with atrial Maze operation.

If IART episodes are infrequent (less than 1 per year or so), well tolerated, and recognized promptly, it may be sufficient to rely on periodic cardioversion rather than embark on therapy with potent antiarrhythmic drugs or invasive procedures. In such cases, a chronic AV node–blocking agent (digoxin, beta blocker, or calcium channel blocker) may be prescribed to reduce the risk of a rapid ventricular response during subsequent episodes, and chronic anticoagulation is usually prescribed as well. If the episodes are frequent, cause significant symptoms, go unrecognized by the patient for a long time, or are associated with atrial thrombus formation (645), 1 or more of the aggressive treatment options must be considered. This is particularly true for patients with extremely dilated right atria and patients with hemodynamic concerns such as reduced function of their single ventricle, AV valve regurgitation, or pulmonary vein compression. As discussed in Section 1.9, Recommendations for Arrhythmia Diagnosis and Management, options for aggressive therapy include pacemaker implantation to reverse bradycardia or provide automatic atrial antitachycardia therapy (150,155), drug therapy (149), catheter ablation (159), and surgical revision of the Fontan connection combined with an atrial Maze operation (160). The choice must be tailored to the hemodynamic and electrophysiological status of the individual patient.

14.10.2. Other Issues to Evaluate and Follow-Up

Ventricular dysfunction, congestive heart failure, cyanosis, and symptomatic arrhythmias are all relatively frequent findings on long-term follow-up and require management directed by an ACHD center as defined in these guidelines. See key issues to monitor in adults with tricuspid atresia/single ventricle in Table 18.

Table 18. Key Issues to Monitor in Adults With Tricuspid Atresia/Single Ventricle

Unoperated patients or those palliated only with a systemic arterial-to-PA shunt:
- Assessment for cavopulmonary connection or Fontan operation: pulmonary pressure/resistance, PA stenosis/distortion, ventricular systolic function, hypertrophy/diastolic function, valvular regurgitation, systemic venous anatomy, obstructions to pulmonary or systemic flow, size of ASD/VSD/BVF, pulmonary venous anatomy
- Catheterization/interventions to improve hemodynamics: stenting of PAs, coarctation; closure of abnormal vessels: PDA, collateral vessels
- Ventricular function assessment: medical treatment options
- Assessment of and treatment for pulmonary vascular disease if present
- Arrhythmia/conduction disorders: diagnosis, management
- Scoliosis/pulmonary function
- Sexuality/contraception/pregnancy issues
- Airline travel
- Exercise participation

After superior vena cava–to–PA anastomosis or Fontan operation: all of the above, plus the following:
- Thromboembolism prevention/treatment
- Postoperative cyanosis: catheterization/intervention/occlusion of right-to-left shunts
- Pulmonary arteriovenous malformations with cyanosis
- Pulmonary vein obstruction
- Protein-losing enteropathy
- Plastic bronchitis[637]
- Arrhythmia management, including surgical conversion from RA or RV-PA connection to lateral tunnel with cryoablation[632]

PA indicates pulmonary artery; ASD, atrial septal defect; VSD, ventricular septal defect; BVF, bulboventricular foramen; PDA, patent ductus arteriosus; RA, right artery; and RV-PA, right ventricular–pulmonary artery.

14.10.3. Recommendations for Endocarditis Prophylaxis

CLASS IIa

1. Antibiotic prophylaxis before dental procedures that involve manipulation of gingival tissue or the periapical region of teeth or perforation of the oral mucosa is reasonable in those patients with the following indications:
   - **a. Prosthetic cardiac valve. (*Level of Evidence: B*)**
   - **b. Previous IE. (*Level of Evidence: B*)**
   - **c. Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: B*)**
   - **d. Completely repaired CHD with prosthetic materials, whether placed by surgery or catheter intervention, during the first 6 months after the procedure. (*Level of Evidence: B*)**
   - **e. Repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device that inhibit endothelialization. (*Level of Evidence: B*)**

2. It is reasonable to consider antibiotic prophylaxis against IE before vaginal delivery at the time of membrane rupture in select patients with the highest risk of adverse outcomes. This includes patients with the following indications:
   - **a. Prosthetic cardiac valve or prosthetic material used for cardiac valve repair. (*Level of Evidence: C*)**
   - **b. Unrepaired and palliated cyanotic CHD, including surgically constructed palliative shunts and conduits. (*Level of Evidence: C*)**

CLASS III

1. Prophylaxis against IE is not recommended for nondental procedures (such as esophagogastroduodenoscopy or colonoscopy) in the absence of active infection. (*Level of Evidence: C*)

14.10.4. Activity

Exercise guidelines are available in the 36th Bethesda Conference report (49). All patients who are not severely limited by symptoms at rest should be encouraged to have an active lifestyle.

14.10.5. Recommendations for Reproduction

CLASS I

1. **All women with a Fontan operation should have a comprehensive evaluation by a physician with expertise in ACHD before proceeding with a pregnancy. (*Level of Evidence: C*)**

CLASS III

1. **Pregnancy should not be planned without consultation and evaluation at a comprehensive ACHD center with experience and expertise in maternal and prenatal management of complex CHD. (*Level of Evidence: C*)**

Successful pregnancy has been reported in postoperative Fontan patients, but atrial arrhythmias, ventricular dysfunction, edema, and ascites have been reported as maternal complications (646,647). In addition, there is an increased risk for spontaneous abortion and premature birth. For those patients undergoing warfarin anticoagulation, this poses the additional risk of fetal exposure in the first trimester and resulting fetal embryopathy. In each case, management must be individualized.

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Appendixes

Appendix 1. Author Relationships With Industry and Other Entities—ACC/AHA 2008 Guidelines for the Management of Adults With Congenital Heart Disease

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Appendix 2. Peer Reviewer Relationships With Industry and Other Entities—ACC/AHA 2008 Guidelines for the Management of Adults With Congenital Heart Disease

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(*Continued*)

Appendix 2. Continued

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*Significant (greater than $10 000) relationship.

Appendix 3. Abbreviations List

ACE = angiotensin-converting enzyme
ACHD = adult congenital heart disease
ALCAPA = anomalous left coronary artery from the pulmonary artery
AR = aortic regurgitation
AS = aortic stenosis
ASD = atrial septal defect
ASO = arterial switch operation
AV = atrioventricular
AVR = aortic valve replacement
AVSD = atrioventricular septal defect
BAV = bicuspid aortic valve
BNP = brain natriuretic peptide
CAVF = coronary arteriovenous fistula
CCTGA = congenitally corrected transposition of the great arteries
CHD = congenital heart disease
CHD-PAH = congenital heart disease–related pulmonary arterial hypertension
CT = computed tomography
d-TGA = dextro-transposition of the great arteries
ECG = electrocardiogram
IART = intra-atrial reentrant tachycardia
IE = infective endocarditis
LV = left ventricular
LVOT = left ventricular outflow tract
MRI = magnetic resonance imaging
PAH = pulmonary arterial hypertension
PDA = patent ductus arteriosus
PFO = patent foramen ovale
PLE = protein-losing enteropathy
PS = pulmonary stenosis
PVR = pulmonary vascular resistance
Qp = pulmonary blood flow
Qs = systemic blood flow
RV = right ventricular
RVOT = right ventricular outflow tract
SAVV = systemic atrioventricular valve
SubAS = subaortic stenosis
SupraAS = supravalvular aortic stenosis
SV = systemic ventricle
TEE = transesophageal echocardiography
TGA = transposition of the great arteries
TR = tricuspid regurgitation
TTE = transthoracic echocardiography
VACA = valvuloplasty and angioplasty of congenital anomalies
VSD = ventricular septal defect
VT = ventricular tachycardia

Appendix 4. Definitions of Surgical Procedures for the Management of Adults With CHD

Arterial Switch Operation (Jatene Procedure)

An operation used in complete TGA that involves removal of the aorta from its attachment to the right ventricle and of the pulmonary artery from the left ventricle. Reattachment of the great arteries to the contralateral ventricles is performed, with reimplantation of the coronary arteries into the neoaorta. This results in the left ventricle supporting the systemic circulation. A LeCompte procedure is often performed, which involves translocation of the pulmonary artery confluence anterior to the ascending aorta.

Atrial Switch Procedure

A procedure that redirects systemic and pulmonary venous return to the contralateral ventricle. When used in complete TGA (either Mustard or Senning procedure), this accomplishes physiological correction of the circulation while leaving the right ventricle to support the systemic circulation. In patients with CCTGA and in those who have had a previous Mustard or Senning procedure, it is used as part of a "double-switch procedure" that results in anatomic correction of the circulation, which results in the left ventricle supporting the systemic circulation.

Baffes Procedure

Anastomosis of the right pulmonary veins to the right atrium and of the inferior vena cava to the left atrium by use of an aortic homograft to connect the inferior vena cava to the left atrium. This operation provides partial physiological correction in patients with complete TGA.

Bentall Procedure

Replacement of the ascending aorta and aortic valve with a valved conduit (composite graft-valve device) with reimplantation of the coronary ostia into the sides of the conduit. The prosthetic valve may be tissue or mechanical.

Blalock-Hanlon Atrial Septectomy

A palliative procedure to improve systemic arterial oxygen saturation in patients with complete TGA. A surgical atrial septectomy is accomplished through a right thoracotomy, excising the posterior aspect of the interatrial septum to provide mixing of systemic and pulmonary venous return at the atrial level.

Blalock-Taussig Shunt

A palliative operation that increases pulmonary blood flow and enhances systemic oxygen saturation. It involves the creation of an anastomosis between a subclavian artery and ipsilateral pulmonary artery either directly with an end-to-side anastomosis (classic) or by use of an interposition tube graft (modified).

Brock Procedure

A palliative operation to increase pulmonary blood flow and reduce right-to-left shunting in tetralogy of Fallot. It involves resection of part of the right ventricle infundibulum with a punch or biopsy-like instrument introduced through the RVOT to reduce RVOT obstruction; the VSD remains open. The operation was performed without cardiopulmonary bypass and is now of historical interest only.

Damus-Stansel-Kaye Procedure

A procedure applied to patients with abnormal ventriculoarterial connections who are not suitable for an ASO (eg, TGA and unsuitable coronary artery patterns, double-outlet right

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ventricle with severe SubAS). The procedure involves anastomosis of the proximal end of the transected pulmonary artery in an end-to-side fashion to the ascending aorta to provide blood flow from the SV to the aorta; coronary arteries are not translocated and are perfused in a retrograde fashion. The aortic orifice and VSD (if present) are closed with a patch. A conduit between the right ventricle and the distal pulmonary artery provides venous blood to the lungs.

Double-Switch Procedure

An operation used in patients with CCTGA that results in anatomic correction of the ventricle–to–great artery relationships so that the left ventricle supports the systemic circulation. It includes an arterial switch procedure (Jatene procedure) in all cases, as well as an atrial switch (Mustard or Senning) procedure in the case of levo-TGA.

Fontan Procedure

A palliative procedure for patients with univentricular circulation that involves diversion of systemic venous return directly to the pulmonary artery, usually without the interposition of a subpulmonary ventricle. There are multiple variations that all lead to normalization of systemic oxygen saturation and elimination of volume overload of the SV.

Fontan/Atriopulmonary Connection

A form of the Fontan operation in which an anastomosis is created between the right atrium and the main pulmonary artery. This form of the Fontan operation is usually not performed in the current era.

Fontan/Extracardiac Conduit

Inferior vena cava blood is directed to the pulmonary arteries via an extracardiac conduit (eg, Gore-Tex tube or valveless homograft). The superior vena cava is anastomosed to the right pulmonary artery as a bidirectional cavopulmonary anastomosis.

Fontan Fenestration

Surgical creation of an ASD in the atrial patch or baffle or conduit to provide an escape valve that allows a right-to-left shunt to reduce pressure in the systemic venous circuit at the expense of systemic hypoxemia.

Fontan/Lateral Tunnel

Inferior vena cava blood is directed by means of a baffle (usually Gore-Tex) within the right atrium into the lower portion of the divided superior vena cava or right atrial appendage, which is connected to the pulmonary artery. The upper part of the superior vena cava is connected to the superior aspect of the right pulmonary artery, as in the bidirectional cavopulmonary anastomosis, or is left connected to the right atrium and channeled toward an atriopulmonary connection. In general, the majority of the right atrium is excluded from the systemic venous circuit.

Glenn Shunt (Cavopulmonary Shunt)

A palliative operation for the purpose of increasing pulmonary blood flow and thus increasing systemic oxygen saturation. The procedure includes a direct anastomosis between the superior vena cava and the pulmonary artery. The procedure does not cause SV volume overload.

Classic Glenn Procedure

Anastomosis of the superior vena cava to the distal end of the divided right pulmonary artery with division and/or ligation of the superior vena cava below the anastomosis. This results in the superior vena cava being the only systemic venous return to the right lung. Acquired pulmonary arteriovenous malformations, with associated systemic arterial desaturation, are a common long-term complication because of the absence of hepatic factors to the right lung.

Bidirectional Glenn Shunt (Bidirectional Cavopulmonary Shunt or Anastomosis [BDCPA])

End-to-side anastomosis of the divided superior vena cava to the undivided right pulmonary artery. This results in superior vena cava blood being directed to both right and left pulmonary arteries. Pulmonary arteriovenous malformations are absent with this configuration. Also referred to as a bidirectional cavopulmonary anastomosis or shunt.

Hemi-Fontan

The first part of a "staged" Fontan procedure, sometimes chosen to reduce the morbidity/mortality that might be associated with performance of the completed Fontan at 1 operation. It is a modification of the bidirectional cavopulmonary anastomosis used at some centers for second-stage palliation in patients with single-ventricle physiology, particularly hypoplastic left-sided heart syndrome. The procedure involves an atriopulmonary anastomosis between the dome of the right atrium and the underside of the right pulmonary artery. A Gore-Tex patch (baffle) is then placed in the superior aspect of the right atrium to direct blood flow from the superior vena cava atriocaval junction into the atriopulmonary anastomosis. The Gore-Tex baffle typically extends into the left pulmonary artery behind the aorta, thus augmenting the central pulmonary artery area.

Ilbawi Procedure

An operation for CCTGA with VSD and PS in which a communication is established between the left ventricle and the aorta via the VSD with a baffle within the right ventricle. The right ventricle is connected to the pulmonary artery by a valved conduit. An atrial switch procedure is performed. The left ventricle then supports the systemic circulation.

Konno-Rastan Procedure

Repair of tunnel-like subvalvular LVOT obstruction by aortoventriculoplasty. The procedure involves enlargement of the LVOT by insertion of a patch in the ventricular septum and performance of AVR with enlargement of the aortic annulus and ascending aorta.

Maze Procedure

An antiarrhythmia procedure designed to treat atrial fibrillation and/or atrial flutter. The original procedure (Cox-Maze

III) involves a series of right and left atrial incisions with selected cryoablation at the tricuspid, mitral annuli, and coronary sinus sites. Modifications of this original procedure include performing right- or left-sided lesions only. In addition, various cryoablation and radiofrequency devices are available to simplify the original procedure.

Mustard Procedure

An atrial switch operation for complete TGA in which venous return is directed to the contralateral ventricle by means of an atrial baffle made from autologous pericardium or synthetic material (eg, Gore-Tex) after resection of most of the atrial septum. This results in the right ventricle supporting the systemic circulation.

Norwood Procedure

A procedure for hypoplastic left heart syndrome. The procedure involves aortic arch reconstruction and creation of an anastomosis between the main pulmonary artery and the neoaorta. An atrial septectomy is performed. In addition, a systemic–to–pulmonary arterial shunt is created (from the brachiocephalic artery to the right pulmonary artery), or a shunt from the right ventricle to the pulmonary artery (Sano modification) is performed. The Norwood procedure is usually followed later by a Glenn shunt and subsequently a Fontan-type procedure, which results in single-ventricle physiology.

Palliative Operation

A procedure performed for the purposes of relieving symptoms or ameliorating some of the adverse effects of a congenital anomaly that does not address the fundamental anatomic or physiological disturbance. This is in contrast to "complete repair" or "reparative" or "corrective" operation.

Potts Shunt

A palliative operation for the purpose of increasing pulmonary blood flow and enhancing systemic oxygen saturation. The procedure involves the creation of a small communication between a pulmonary artery and the ipsilateral descending thoracic aorta. This is most often performed on the left side with situs solitus of the atria and viscera. It often results in the development of pulmonary vascular obstructive disease if the communication is too large or acquired stenosis and/or atresia of the pulmonary artery if distortion occurs.

Pulmonary Artery Banding

Surgically created stenosis of the main pulmonary artery performed as a palliative procedure to protect the lungs against high pulmonary blood flow and pressure when definitive repair of the underlying congenital anomaly is not immediately advisable or recommended (eg, multiple VSDs, Swiss cheese septum). More commonly performed in an earlier surgical era when neonatal repair for complex CHD was not feasible.

Pulmonary Vein Isolation Procedure

An encircling incision, cryoablation, or radiofrequency application performed on the left atrium adjacent to the origins of the left- and right-sided pulmonary veins.

Rashkind Procedure

A balloon atrial septostomy performed via cardiac catheterization as a palliative procedure to allow mixing of systemic and pulmonary venous return in children with complete TGA.

Rastelli Procedure

An operation for repair of complete TGA in association with a large VSD and LVOT obstruction. A communication is established between the left ventricle and the aorta by VSD closure with a baffle within the right ventricle. The right ventricle is connected to the pulmonary artery by a valved conduit, and the left ventricle–to–pulmonary artery connection is obliterated. As a consequence, the left ventricle supports the systemic circulation.

Ross Procedure

A method of aortic valve replacement that involves autograft transplantation of the pulmonary valve, annulus, and main pulmonary artery into the aortic position with reimplantation of the coronary ostia into the neoaorta. The RVOT is usually reconstructed with a pulmonary homograft conduit.

Senning Procedure

An atrial switch operation for complete TGA in which venous return is directed to the contralateral ventricle by means of an intra-atrial baffle fashioned in situ by use of the right atrial wall and interatrial septum. As a consequence, the right ventricle supports the systemic circulation.

Switch Conversion of TGA (Double Switch)

An operation performed in patients with CCTGA. This allows the left ventricle to assume the function of the SV. The first stage may involve pulmonary artery banding to induce hypertrophy of the morphological left ventricle. The second stage involves an arterial switch procedure and a Mustard or Senning operation.

Takeuchi Procedure

A technique to repair an anomalous left coronary artery from the pulmonary artery (ALCAPA) when the position of the left coronary orifice does not allow direct reimplantation into the aorta. The procedure consists of a baffle of pulmonary artery tissue to reroute the ALCAPA into the aorta via an intrapulmonary baffle.

Valve-Sparing Aortic Root Replacement

A surgical procedure for an ascending aortic aneurysm involving the sinuses of Valsalva that involves resection of the aortic root with mobilization of the coronary ostia. The aortic root is reconstructed with a tube graft, with resuspension of the native aortic valve within the graft and reimplantation of the coronary ostia.

Ventricular Repair

1-Ventricle Repair: See Fontan procedure.

1.5-Ventricle Repair: A term used to describe a procedure for cyanotic CHD performed when the pulmonary ventricle is insufficiently developed to accept the entire systemic venous return. A bidirectional cavopulmonary connection is con-

structed to direct superior vena cava blood flow directly to the pulmonary arteries, whereas the inferior vena caval blood flow is directed to the lungs via the small pulmonary ventricle.

2-Ventricle Repair: A term used to describe operations for cyanotic CHD with common ventricle or adequately sized pulmonary and systemic ventricles that communicate via a VSD. The pulmonary and systemic circulations are septated surgically by placement of an intraventricular patch (for common ventricle) or VSD patch (for separate pulmonary ventricle and SV cavities).

Warden Procedure

Technique to repair partial anomalous pulmonary venous connection to the superior vena cava, usually with an associated sinus venosus ASD. The superior vena cava is transected above the most proximal anomalous pulmonary vein; the proximal superior vena cava is then anastomosed to the right atrial appendage. The superior vena cava–right atrial junction is closed by patch, and the superior vena cava with the anomalous draining pulmonary veins is left draining to the left atrium via the sinus venosus ASD. The azygous vein is ligated. This technique is particularly useful when the anomalous pulmonary veins are draining into the mid and upper superior vena cava.

Waterston Shunt

A palliative operation for the purpose of increasing pulmonary blood flow and enhancing systemic oxygen saturation that involves creation of a small communication between the right pulmonary artery and the ascending aorta. It is often complicated by the development of pulmonary vascular obstructive disease if the communication is too large. It also may cause distortion of the pulmonary artery.

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