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■ ■NOVEL DEVICES Newer pumps are in development that are designed to overcome chal lenges inherent in current-generation LVAS. Engineering continues to advance in this field, and we await devices that provide physiologic and synchronized pulsatile flow (rather than the unnatural transapical to aortic flow with current LVADs). The next paradigm shift will likely require a return to natural and pulsatile flow LVAS that are more bio compatible (as opposed to hemocompatible), responsive to physiologic requirements (smart pumps), and forgettable (without an external driveline to power its components). ■ ■TOTAL ARTIFICIAL HEART Not all patients are candidates for an LVAS, particularly those with severe right-sided heart failure or conditions that do not allow place ment of an LVAS (restrictive cardiomyopathy, cardiac amyloidosis, massive anterior myocardial infarction, complex congenital heart disease). In such patients, either a biventricular assist device approach or a total artificial heart pump can be considered. The SynCardia total artificial heart is a pulsatile, implantable pump that consists of two polyurethane ventricles with pneumatically driven diaphragms and four tilting disc valves. This requires excision of the native ventricles and thus cannot be employed as a myocardial recovery strategy. There are specific clinical issues that are unique to the total artificial heart management. This device operates on a steep physiologic curve and has little adaptability to tolerate either systemic blood pressure changes or large shifts in blood volume. As the ventricles are excised, most patients exhibit a sharp decline in renal function due to the loss of natriuretic peptide expression by the myocardium. Severe hemolysis is common due to the presence of four mechanical valves, and aberrant erythropoi esis is noted, leading to a severe anemia. Newer artificial hearts using biocompatible surfaces are under study (CARMAT), as well as those that use continuous flow technology (BIVACOR). ■ ■XENOTRANSPLANTATION On January 7, 2022, the first genetically edited pig-to-human heart xenotransplantation was performed. The porcine xenograft was derived from a 10-gene edited animal with four genes that were knocked out (targeting three carbohydrate antigens associated with hyperacute rejection and one anticardiac growth gene) and six genes that were knocked in (targeting human complement regulation, coagulation, and anti-inflammatory pathways). Two transplants have been performed in living human recipients with limited survival of 2 months or less, with death occurring due to delayed graft dysfunction and subsequent loss. There are substantial ongoing concerns with continued immunologic barriers (despite gene modification), costs of donor organ development and recovery, ethical considerations, and considerations of transmis sion of zoonoses. ■ ■GLOBAL CONSIDERATIONS While LVAS are available worldwide, their use and indications vary from country to country. In the United States, payers used to require discrete discrimination of indication into either a bridge to transplant or destination therapy, whereas in most European countries, this artificial segregation was not used. Cost-effectiveness studies suggest improvement with the newer devices, yet some countries only allow use of this technology as a bridge to transplantation (United King dom) while awaiting more definitive long-

term studies for lifetime use. The use of LVAS in moderately symptomatic ambulatory patients with chronic systolic heart failure is still discouraged throughout the world, awaiting the availability of devices that can be fully internal ized without the need for an external driveline. Globally, the rates of myocardial recovery allowing for decommissioning or removal of devices remain low, although in young patients with nonischemic heart failure of relatively recent onset, this could be an important consideration. ■ ■FURTHER READING Crespo-Leiro MG et al: Heart transplantation: Focus on donor recov ery strategies, left ventricular assist devices, and novel therapies. Eur Heart J 43:2237, 2022.

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Aortic Stenosis GLOBAL BURDEN OF VALVULAR HEART DISEASE Valvular heart disease ranks well below ischemic heart disease, stroke, hypertension, obesity, and diabetes as a major threat to the public health. Nevertheless, it can cause significant morbidity and lead to premature death. Rheumatic fever (Chap. 371) is the dominant cause of valvular heart disease in low- and middle-income countries. Its prevalence has been estimated to range from as low as 1 per 100,000 school-age children in Costa Rica to as high as 150 per 100,000 in China (Fig. 272-1). Prevalence is higher among females than males, especially for individuals age 20–40 years. Rheumatic heart disease accounts for 12–65% of hospital admissions related to cardiovascular disease and 2–10% of hospital discharges in some endemic countries. Prevalence and mortality rates vary among communities even within the same country as a function of overcrowding, the availability of medical resources, education level, and population-wide programs for detection and treatment of group A streptococcal pharyngitis. In economically deprived areas, tropical and subtropical climates (par ticularly on the Indian subcontinent and in Southeast Asia), Central America, and the Middle East, rheumatic valvular disease progresses more rapidly than in more developed nations and frequently causes serious symptoms in patients aged <20 years. This accelerated natural history may be due to repeated infections with more virulent strains of rheumatogenic streptococci. Approximately 45–50 million people (575.5 per 100,000) live with rheumatic heart disease worldwide, an estimated prevalence characterized by 300,000 new cases and 233,000 case fatalities (5 per 100,000) per year, with the highest prevalence and age-adjusted mortality rates in sub-Saharan Africa, South Asia, Central Asia, and Oceania. In the United States, rheumatic heart disease accounted for 3876 deaths in 2020. Although globally the agestandardized mortality

rate from rheumatic heart disease declined by nearly 50% between 1990 and 2022, the prevalence of heart failure attributable to rheumatic heart disease increased by nearly 90% over the same time interval.

PART 6 Disorders of the Cardiovascular System < 2.16 2.16 to < 4.17 4.17 to < 6.19 6.19 to < 8.2 8.2 to < 10.21 10.21 to < 12.23 12.23 to < 14.24 14.24 to < 16.25 16.25 to < 18.27

> “ = 18.27 A YLDs (Years Lived with Disability)

YLLs (Years of Life Loot)

Rate per 100,000

DALYs (Disability Adjusted Life Years)

Year B FIGURE 272-1 The global burden of rheumatic heart disease. (A) Global map of age-standardized rheumatic heart disease morality rate per 100,000 in 2022. Mortality rates are highest in South Asia and Oceania. (B) Global rheumatic heart disease estimates per 100,000 by measure with shaded 95% uncertainty interval, 1990–2022. DALYs, disability-adjusted life-years; YLDs, years lived with disability; YLLs, years of life lost. (Reproduced with permission from GA Mensah et al: Global burden of cardiovascular diseases and risks, 1990-2022. J Am Coll Cardiol 82:2350, 2023.)

Prevalence

Mortality

All Ages Age-standardized

Prevalence of moderate or severe valve All valve disease Mitral valve disease Aortic valve disease

disease (%)

<45 45–54 53–64 65–74 ≥75 FIGURE 272-2 The burden of moderate or severe mitral and aortic valve disease in the United States. Prevalence estimates are derived from three population-based studies comprising a total of 11,911 individuals: The Coronary Artery Risk Development in Young Adults (CARDIA), the Atherosclerosis Risk in Communities (ARIC), and the Cardiovascular Health Study (CHS). (Reproduced with permission from VT Nkomo, JM Gardin, TN Skelton, et al: Burden of valvular heart diseases: a population-based study, Lancet 368(9540):1005-1011, 2006.) Valve disease in high-income countries is dominated by degen erative or nonrheumatic inflammatory processes that lead to valve thickening, fibrosis, calcification, and dysfunction. The prevalence of valvular heart disease increases significantly with age. Community echocardiographic screening identifies previously undiagnosed, pre dominantly mild valvular heart disease in ~50% of the population aged >65 years. In this age group, the prevalence of previously undi agnosed moderate or severe valvular heart disease is ~6%. Significant left-sided valve disease may affect as many as

12–13% of adults aged

> 75 years (Fig. 272-2). Severe aortic stenosis (AS) is estimated to affect 3.5% of the population aged >75 years. A Swedish epidemio logic study estimated the incidence of newly diagnosed valvular heart disease at 64 per 100,000 person-years, with approximately 70% of incident disease observed in individuals 65 years of age or older. AS and mitral regurgitation contributed approximately one-half and one-quarter, respectively, of the valvular heart disease diagnoses in this study. The incidence of infective endocarditis (Chap. 133) has increased with the aging of the population, the more widespread prevalence of vascular grafts and intracardiac devices, the emergence of more viru lent multidrug-resistant microorganisms, and the growing epidemic of injection drug use. North American age-standardized incidence rates for endocarditis increased from in 10.1 per 100,000 population in 1990 to 12.54 per 100,000 population in 2019. The more restricted use of antibiotic prophylaxis since 2007 has not been convincingly associated with an increase in incidence rates for infective endocar ditis cases attributable to oropharyngeal pathogens. Infective endo carditis has become a relatively more frequent cause of acute valvular regurgitation. Valve surgery during the acute phase of infective endo carditis is performed in ~50–60% of hospitalized patients. Duration of intravenous antibiotic use may be shortened in selected cases. Bicuspid aortic valve (BAV) disease affects as many as 0.5–1.4% of the general population and is accompanied by an associated aor topathy in ~30–40% of individuals, a disease process expressed as root or ascending aortic aneurysm formation or descending thoracic aortic coarctation. An increasing number of childhood survivors of congenital heart disease present later in life with valvular dysfunction. The global burden of valvular heart disease will continue to progress. As is true for many other chronic health conditions, disparities in access to and quality of care for patients with valvular heart dis ease have been well documented, especially for those patients with rheumatic heart disease in low- and middle-income countries. In the Society for Thoracic Surgeons (STS)/American College of Cardiology (ACC) Transcatheter Valve Therapy (TVT) registry, black patients

compose <5% of patients in the United States who have received a transcatheter valve for AS. Management decisions and outcome differences based on age, sex, race, geography, and other social determinants of health require intensification of educational efforts and prioritization of resources.

CHAPTER 272 The role of the physical examination in the evaluation of patients with valvular heart disease is also considered in Chaps. 44 and 246; of electrocardiography (ECG) in Chap. 247; of echocardiography and other noninvasive imag ing techniques in Chap. 248; and of cardiac catheterization and angiography in Chap. 249. Aortic Stenosis AORTIC STENOSIS AS is the most common valve lesion among adult patients with chronic valvular heart disease; the majority of adult patients with symptomatic, valvular AS are male. ■ ■ETIOLOGY AND PATHOGENESIS (Table

272-1) AS in adults is due to degenerative calcification of the aortic cusps and occurs most commonly on a substrate of congenital disease (BAV), chronic (trileaflet) deterioration, or previous rheumatic inflammation. A pathologic study of specimens removed at the time of aortic valve replacement (AVR) for AS in adults showed that 53% were bicuspid and 4% were unicuspid. The process of aortic valve deterioration and calcification is not a passive one, but, rather, one that shares many features with vascular atherosclerosis, including endothelial dys function, lipid accumulation, inflammatory cell activation, cytokine release, and upregulation of several signaling pathways (Fig. 272-3). Eventually, a fibrocalcific response is established wherein collagen is deposited and valvular myofibroblasts differentiate phenotypically into osteoblasts and actively produce bone matrix proteins that allow for the deposition of calcium hydroxyapatite crystals. Genetic poly morphisms involving the vitamin D receptor, the estrogen receptor in postmenopausal women, interleukin 10, and apolipoprotein E4 have been linked to the development of calcific AS, and a strong familial clustering of cases with trileaflet valves has been reported from west ern France. Several traditional atherosclerotic risk factors have also been associated with the development and progression of calcific AS, including hypertension, low-density lipoprotein (LDL) cholesterol, lipoprotein(a) (Lp[a]), diabetes mellitus, smoking, chronic kidney disease, and the metabolic syndrome. In a Canadian observational cohort study, the incidence of severe AS was 144 per 100,000 personyears. Hypertension, diabetes mellitus, and dyslipidemia accounted for approximately one-third of the population-attributable risk for severe AS. The presence of aortic valve sclerosis (focal thickening and calcification of the leaflets not severe enough to cause obstruction) is associated with an excess risk of cardiovascular death and myocardial infarction (MI) among persons aged >65. Approximately 30% of per sons aged >65 years exhibit some degree of aortic valve sclerosis. Rate and extent of progression to valve obstruction (stenosis) vary among individual patients. Rheumatic disease of the aortic leaflets produces commissural fusion, sometimes resulting in a bicuspid-appearing valve. This con dition, in turn, makes the leaflets more susceptible to trauma and ultimately leads to fibrosis, calcification, and further narrowing. By the time obstruction to left ventricular (LV) outflow causes serious clinical disability, the valve is usually a rigid calcified mass, and care ful examination may make it difficult or even impossible to determine TABLE 272-1 Major Causes of Aortic Stenosis VALVE LESION ETIOLOGIES Aortic stenosis Congenital (bicuspid, unicuspid) Degenerative calcific disease Rheumatic fever Radiation

Lipid infiltration Inflammation Fibro-calcific response Radiation Mechanical stress Lipid-derived species Cytokines PART 6 Disorders of the Cardiovascular System LDL Lp(a) NOS uncoupling ROS ACE Chymase Ox-LDL Ox-PL Lp-PLA2 MMPs VEGF TNF IL-1β lysoPC ATX lysoPA IL-6 WNT3a ATX sPLA2 TGFβ LPAR BMP2 ENPP1 VIC AA ATP AMP +PPi COX2 5-LO ALP Prostaglandins Leukotrienes Pi FIGURE 272-3 Pathogenesis of calcific aortic stenosis. Lipid and inflammatory cell infiltration occurs across damaged endothelium. A cascade of events follows that leads eventually to formation of disorganized collagen (fibrosis) and calcium hydroxyapatite (bone) deposition. Valvular interstitial cells (VIC) are critical participants in this active process. AA, arachidonic acid; ACE, angiotensin-converting enzyme; ALP, alkaline phosphatase; ApoB, apolipoprotein B; AMP, adenosine monophosphate; ATP, adenosine triphosphate; ATX, autotaxin; A2AR, adenosine A2A receptor; BMP, bone morphogenetic protein; COX2, cyclooxygenase 2; ENPP, ectonucleotide pyrophosphatase/ phosphodiesterase; IL, interleukin; 5-LO, 5-lipoxygenase; LDL, low-density lipoprotein; Lp(a), lipoprotein(a); LPAR, lysophosphatidic acid receptor; Lp-PLA2, lipoproteinassociated phospholipase A2; lysoPA, lysophosphatidic acid; lysoPC, lysophosphatidylcholine; MMP, matrix metalloproteinase; NOS, nitric oxide synthase; Ox-PL,

oxidized phospholipid; Ox-LDL, oxidized LDL; RANKL, receptor activator of nuclear factor-κB ligand; ROS, reactive oxygen species; RUNX2, runt-related transcription factor 2; sPLA2, secreted PLA2; TGFβ, transforming growth factor β; TNF, tumor necrosis factor; VEGF, vascular endothelial growth factor; VIC, valvular interstitial cell. (Reproduced with permission from B Lindman et al: Calcific aortic stenosis. Nat Rev Dis Primers 2:16006, 2016.) the etiology of the underlying process. Rheumatic AS is almost always associated with involvement of the mitral valve and with aortic regur gitation (AR). Mediastinal radiation can also result in late scarring, fibrosis, and calcification of the aortic leaflets. In this context, the calcification process also affects the mitral annulus. ■ ■BICUSPID AORTIC VALVE DISEASE A bicuspid aortic valve (BAV) is the most common congenital heart valve defect and occurs in 0.5–1.4% of the population with a 2–4:1 male-to-female predominance. The inheritance pattern appears to be autosomal dominant with incomplete penetrance, although some have questioned an X-linked component as suggested by the preva lence of BAV disease among patients with Turner's syndrome. The prevalence of BAV disease among first-degree relatives of an affected individual is ~10%. A single gene defect to explain the majority of cases has not been identified, although mutations in the NOTCH1, GATA5, and GATA4 genes have been described in some families. Abnormalities in endothelial nitric oxide synthase and NKX2.5 have been implicated as well. Medial degeneration with ascending aortic aneurysm formation occurs commonly among patients with BAV disease; aortic coarctation is less frequently encountered. Patients with BAV disease have larger aortas than patients with comparable tricuspid aortic valve disease. The aortopathy develops independently of the hemodynamic severity of the valve lesion, but directional shear forces dictated by the anatomic configuration of the valve appear to influence its expression. For example, enlargement of the

Lipids Calcium hydroxyapatite Blood vessel Angiotensin I VEGF LDL Osteoprogenitor cell Angiotensin II inflammation RANKL TNF Collagen Apoptosis Osteogenic transition RUNX2 MSX2 Fibrosis A2AR NT5E Macrophage Monocyte Mineralization Mastocyte Calcifying microvesicles Adenosine +Pi T cell Time ascending aorta along its greater curvature is most often associated with right-left cusp fusion (Sievers classification type 1), the most common bicuspid variant. Patients with BAV disease are at risk for aneurysm formation and/or dissection. A BAV can be a component of more complex congenital heart disease with or without other left heart obstructing lesions, as seen in Shone's complex (supravalvar mitral membrane, parachute mitral valve, subvalvar AS, and aortic coarctation). ■ ■OTHER FORMS OF OBSTRUCTION TO LEFT VENTRICULAR OUTFLOW In addition to valvular AS, three other lesions may be responsible for obstruction to LV outflow: hypertrophic obstructive cardiomyopathy (Chaps. 266–270), discrete fibromuscular/membranous subaortic ste nosis, and supravalvular AS (Chap. 280). The causes of LV outflow obstruction can usually be differentiated on the basis of the cardiac examination and Doppler echocardiographic findings. ■ ■PATHOPHYSIOLOGY The obstruction to LV outflow produces a systolic pressure gradi ent between the LV and aorta. When severe obstruction is suddenly produced experimentally, the LV responds by dilation and reduction of stroke volume. However, in some patients, the obstruction may be present at birth and/or increase gradually over the course of many years, and LV contractile performance is maintained by the presence of concentric LV hypertrophy. Initially, this serves as an adaptive

mechanism because it reduces toward normal the systolic stress developed by the myocardium, as predicted by the Laplace relation wall tension normalized to wall thickness ($S = Pr/h$, where S = systolic wall stress, P = pressure, r = radius, and h = wall thickness). A large transaortic valve

pressure gradient may exist for many years without a reduction in cardiac output (CO) or the development of LV dilation. Ultimately, however, excessive hypertrophy becomes maladaptive, LV systolic function declines because of afterload mismatch, abnormali ties of diastolic function progress, and irreversible myocardial fibrosis develops. A mean systolic pressure gradient >40 mmHg with a normal CO or an effective aortic orifice area of ~<1 cm2 (or ~<0.6 cm2/m2 body surface area in a normal-sized adult)—i.e., less than approximately one-third of the normal orifice area—is generally considered to represent severe obstruction to LV outflow. The elevated LV enddiastolic pressure observed in many patients with severe AS and preserved ejection fraction (EF) signifies the presence of diminished compliance of the hypertrophied LV. Although the CO at rest is within normal limits in most patients with severe AS, it usually fails to rise normally during exercise. Loss of an appropriately timed, vigorous atrial contraction, as occurs in atrial fibrillation (AF) or atrioventricular dissociation, may cause rapid progression of symptoms. Late in the course, contractile function deteriorates because of afterload excess, the CO and LV–aortic pressure gradient declines, and the mean left atrial (LA), pulmonary artery (PA), and right ventricular (RV) pressures rise. LV performance can be further compromised by superimposed epicardial coronary artery disease (CAD). Stroke volume (and thus CO) can also be reduced in patients with significant hypertrophy and a small LV cavity despite a normal EF. Low-flow (defined as a stroke volume index <35 mL/m2), lowgradient (defined as a mean pressure gradient <40 mmHg) AS (with either reduced or normal LV systolic function) is both a diagnostic and therapeutic challenge. The hypertrophied LV causes an increase in myocardial oxygen requirements. In addition, even in the absence of obstructive CAD, coronary blood flow is impaired to the extent that ischemia can be precipitated under conditions of excess demand. Capillary density is reduced relative to wall thickness, compressive forces are increased, and the elevated LV end-diastolic pressure reduces the coronary driv ing pressure. The subendocardium is especially vulnerable to ischemia by this mechanism. ■ ■SYMPTOMS AS is rarely of clinical importance until the valve orifice has narrowed to ~1 cm2. Even severe AS may exist for many years without produc ing any symptoms because of the ability of the hypertrophied LV to generate the elevated intraventricular pressures required to maintain a normal stroke volume. Once symptoms occur, or the LV ejection frac tion falls below normal, valve replacement is indicated. Most patients with pure or predominant AS have gradually increasing obstruction over years but do not become symptomatic until the sixth to eighth decades. Adult patients with BAV disease, however, develop significant valve dysfunction and symptoms one to two decades sooner. Exertional dyspnea, angina pectoris, and syncope are the three cardinal symptoms. Often, there is a history of insidious progression of fatigue and dyspnea associated with gradual curtailment of activities and reduced effort tolerance. Dyspnea results primarily from elevation of the pulmonary capillary pressure caused by elevations of LV diastolic pressures secondary to impaired relax ation and reduced LV compliance. Angina pectoris usually develops somewhat later and reflects an imbalance between the increased myocardial oxygen requirements and reduced oxygen availability. CAD may or may not be present, although its coexistence is com mon among AS patients age >65. Exertional syncope may result from a decline in arterial pressure caused by vasodilation in exercising muscles and inadequate vasoconstriction in nonexercising muscles in the face of a fixed CO, or from a sudden fall in CO produced by an arrhythmia.

Because the CO at rest is usually well maintained until late in the course, marked fatigability, weakness, peripheral cyanosis, cachexia, and other clinical manifestations of a low CO are usually not promi nent until this stage is reached. Orthopnea, paroxysmal nocturnal dyspnea, and

pulmonary edema, i.e., symptoms of LV failure, also occur only in the advanced stages of the disease. Severe pulmonary hypertension leading to RV failure and systemic venous hypertension, hepatomegaly, AF, and tricuspid regurgitation (TR) are usually late findings in patients with isolated severe AS.

CHAPTER 272 When AS and mitral stenosis (MS) coexist, the reduction in flow (CO) caused by MS lowers the pressure gradient across the aortic valve and, thereby, masks many of the clinical findings produced by AS. The transaortic pressure gradient can be increased in patients with con comitant AR due to higher aortic valve flow rates. Aortic Stenosis ■ ■PHYSICAL FINDINGS The heart rhythm is generally regular until late in the course; at other times, AF should suggest the possibility of associated mitral valve disease. Hypertension occurs commonly among older adults with AS. In the late stages, however, when stroke volume declines, the systolic pressure may fall and the pulse pressure narrow. The carotid arterial pulse rises slowly to a delayed peak (pulsus parvus et tardus). A thrill or anacrotic “shudder” may be palpable over the carotid arteries, more commonly the left. In the elderly, the stiffening of the arterial wall may mask this important physical sign. In many patients, the a wave in the jugular venous pulse is accentuated. This results from the diminished distensibility of the RV cavity caused by the bulging, hypertrophied interventricular septum. The LV impulse is sometimes displaced laterally in the later stages of the disease. A double apical impulse (with a palpable S4) may be appreciated, particularly with the patient in the left lateral recumbent position. A systolic thrill may be present at the base of the heart to the right of the sternum when leaning forward or in the suprasternal notch. Auscultation An early systolic ejection sound is frequently audi ble in children, adolescents, and young adults with congenital BAV disease. This sound usually disappears when the valve becomes calci fied and rigid. As AS increases in severity, LV systole may become pro longed so that the aortic valve closure sound no longer precedes the pulmonic valve closure sound, and the two components may become synchronous, or aortic valve closure may even follow pulmonic valve closure, causing paradoxical splitting of S2 (Chap. 246). The sound of aortic valve closure can be heard most frequently in patients with AS who have pliable valves; calcification diminishes the intensity of this sound. Frequently, an S4 is audible at the apex and reflects the presence of LV hypertrophy and an elevated LV end-diastolic pressure; an S3 generally occurs late in the course when the LV dilates and its systolic function becomes severely compromised. The murmur of AS is described as an ejection (mid) systolic mur mur that commences shortly after the S1, increases in intensity to reach a peak toward the middle of ejection, and ends just before aortic valve closure. It is characteristically low-pitched, rough, and rasping in character, and loudest at the base of the heart, most commonly in the second right intercostal space. It is transmitted upward along the carotid arteries. Occasionally, it is transmitted downward and to the apex, where it may be confused with the systolic murmur of mitral regurgitation (MR) (Gallavardin effect). In almost all patients with severe obstruction and preserved CO, the murmur is at least grade III/ VI. In patients with mild degrees of obstruction or in those with severe stenosis with heart failure and low CO in whom the stroke volume and, therefore, the transvalvular flow rate are reduced, the murmur may be relatively soft and brief. ■ ■LABORATORY EXAMINATION ECG In most patients with severe AS, there is LV hypertrophy. In advanced cases, ST-segment depression and T-wave inversion (LV “strain”) in standard leads I and aVL and in the left precordial leads are evident. However, there is no close correlation between the ECG

and the hemodynamic severity of obstruction, and the absence of ECG signs of LV hypertrophy does not exclude severe obstruction. Systemic hypertension can coexist and also contribute to the development of hypertrophy.

Echocardiogram The key findings on transthoracic echocar diogram are thickening, calcification, and reduced systolic opening of the aortic valve leaflets and LV hypertrophy. Eccentric closure of the aortic valve cusps is characteristic of congenitally bicuspid valves. Transesophageal echocardiography imaging can display the obstructed orifice extremely well, but it is not routinely required for accurate characterization of AS. The valve gradient and aortic valve area can be estimated by Doppler measurement of the transaortic velocity. Severe AS is defined by a valve area <1 cm2, whereas moder ate AS is defined by a valve area of 1–1.5 cm2 and mild AS by a valve area of 1.6–2 cm2. Aortic valve sclerosis, conversely, is accompanied by a jet velocity of <2.5 m/s (peak gradient <25 mmHg). LV dilation and reduced systolic shortening reflect impairment of LV function. There is a robust experience with the use of longitudinal strain to characterize earlier changes in LV systolic function before a decline in EF can be appreciated. Doppler indices of impaired diastolic func tion are frequently seen. The frequency with which echocardiography should be repeated during follow-up is dictated by the severity of the stenosis (Table 272-2). PART 6 Disorders of the Cardiovascular System Echocardiography is useful for identifying coexisting valvular abnormalities, differentiating valvular AS from other forms of LV outflow obstruction, and measuring the aortic root and proximal ascending aortic dimensions. These aortic measurements are par ticularly important for patients with BAV disease. Dobutamine stress echocardiography can be useful for the evaluation of patients with AS and severe LV systolic dysfunction (low-flow, low-gradient, severe AS with reduced EF), in whom the severity of the AS can often be difficult to judge. Patients with severe AS (i.e., valve area <1 cm2) with a relatively low mean gradient (<40 mmHg) despite a normal EF (low-flow, low-gradient, severe AS with normal EF) are often hyper tensive, and efforts to control their systemic blood pressure should be optimized before Doppler echocardiography is repeated. The use of dobutamine stress echocardiography in this setting is not advised. When there is continued uncertainty regarding the severity of AS in patients with reduced CO and reduced or normal LVEF, quantitative analysis of the amount of aortic valve calcium with chest computed tomography (CT) can be helpful. Aortic valve calcium scores that define severe AS differ for men and women, as men tend to have relatively more calcification and women more fibrosis of the valve leaflets. There is increasing use of chest CT angiography to assess aortic valve morphology and function. It has become the imaging method of choice to plan for transcatheter aortic valve implanta tion (TAVI). Finally, the use of cardiac magnetic resonance (CMR) imaging to screen for the presence of increased extracellular volume (interstitial fibrosis) and late gadolinium enhancement (replacement fibrosis) in patients with severe AS is an area of active investigation. Future management pathways related to the asymptomatic AS patient are likely to include an integrated assessment of the findings from multimodality imaging studies. Chest X-Ray The chest x-ray may show no or little overall car diac enlargement for many years. Hypertrophy without dilation may produce some rounding of the cardiac apex in the frontal projec tion and slight backward displacement in the lateral view. A dilated TABLE 272-2 Frequency of Follow-Up Echocardiography in Aortic Stenosis STAGE OF DISEASE FREQUENCY OF ECHOCARDIOGRAPHY Progressive (stage B) Every 3–5 years (mild severity, Vmax 2.0–2.9 m/s) Every 1–2 years (moderate severity, Vmax 3.0–3.9 m/s) Severe asymptomatic (stage C1) Every 6–12 months (Vmax >4 m/s)

proximal ascending aorta may be seen along the upper right heart border in the frontal view. Aortic valve calcification may be discern ible in the lateral view, but it is usually readily apparent on fluoro scopic examination or by echocardiography; the absence of valvular calcification on fluoroscopy in an adult suggests that severe valvular AS is not present. In later stages of the disease, as the LV dilates, there is increasing roentgenographic evidence of LV enlargement, pulmonary congestion, and enlargement of the LA, PA, and rightsided heart chambers. Catheterization Right- and left-sided heart catheterization for invasive assessment of AS is performed infrequently but can be useful when there is a discrepancy between the clinical and nonin vasive findings. Concern has been raised that attempts to cross the aortic valve for measurement of LV pressures are associated with a risk of cerebral embolization. Catheterization can also be useful in three distinct categories of patients: (1) patients with multivalvular disease, in whom the role played by each valvular deformity should be defined to aid in the planning of operative treatment; (2) young, asymptomatic patients with noncalcific congenital AS, to define the severity of obstruction to LV outflow, because operation or percuta neous aortic balloon valvuloplasty (PABV) may be indicated in these patients if severe AS is present, even in the absence of symptoms; and (3) patients in whom it is suspected that the obstruction to LV outflow may not be at the level of the aortic valve but rather at the sub- or supravalvular level. Coronary angiography is indicated to screen for CAD in appropriate patients with severe AS who are being considered for surgical or trans catheter valve intervention. Angiography can be performed invasively at the time of catheterization for hemodynamic assessment or with noninvasive CT techniques. Decision-making regarding the need for coronary artery revascularization at the time of aortic valve interven tion is individualized. ■ ■NATURAL HISTORY Death in patients with severe AS occurs most commonly in the seventh and eighth decades. Based on data obtained at postmortem examina tion in patients before surgical treatment became widely available, the average time to death after the onset of various symptoms was as fol lows: angina pectoris, 3 years; syncope, 3 years; dyspnea, 2 years; and heart failure, 1.5–2 years. Moreover, in >80% of patients who died with AS, symptoms had existed for <4 years. Among adults dying with val vular AS, sudden death, which presumably resulted from an arrhyth mia, occurred in 10–20%; however, most sudden deaths occurred in patients who had previously been symptomatic. Sudden death as the first manifestation of severe AS is very uncommon (~1% per year) in asymptomatic adult patients. Calcific AS is a progressive disease, with an annual reduction in valve area averaging 0.1 cm2 and annual increases in peak jet velocity and mean valve gradient averaging 0.3 m/s and 7 mmHg, respectively. TREATMENT Aortic Stenosis (Fig. 272-4) MEDICAL TREATMENT In patients with severe AS (valve area <1 cm2), strenuous physi cal activity and competitive sports should be avoided, even in the asymptomatic stage. Care must be taken to avoid dehydra tion and hypovolemia to protect against a significant reduction in CO. Medications used for the treatment of hypertension or CAD, including beta blockers and angiotensin-converting enzyme (ACE) inhibitors, are generally safe for asymptomatic patients with preserved LV systolic function. Control of blood pressure is important to attenuate the deleterious pathophysiologic effects of two resistance circuits (valve, arterial circulation) in series. Nitroglycerin is helpful in relieving angina pectoris in patients with CAD. Neither HMG-CoA reductase inhibitors (“statins”) nor

Abnormal aortic valve with reduced systolic opening Symptoms due to AS Severe AS stage D1 • Vmax ≥4 m/s or • ΔPmean ≥40 mm Hg Vmax ≥4 m/s and AVA ≤1.0 cm2 LV EF <50% Yes No EF <50% Severe AS stage D2 DSE Vmax ≥4 m/s at any flow rate Severe AS stage D3 AVA1 ≤0.6 cm2/m2 and SVI <35 mL/m2 AS most likely cause of symptoms AVR (SAVR or TAVI) (1) AVR (SAVR

or TAVI) (1) SAVR (2a) SAVR (2b) FIGURE 272-4 Management strategy for patients with aortic stenosis. Preoperative coronary angiography should be performed routinely as determined by age, symptoms, and coronary risk factors. Cardiac catheterization and angiography may also be helpful when there is a discrepancy between clinical and noninvasive findings. Patients who do not meet criteria for intervention should be monitored with clinical and echocardiographic follow-up. The class designations refer to the American Heart Association/ American College of Cardiology methodology for treatment recommendations. Class I recommendations should be performed or are indicated; Class IIa recommendations are considered reasonable to perform; Class IIb recommendations may be considered. The stages refer to the stages of progression of the disease. At disease stage A, risk factors are present for the development of valve dysfunction; stage B refers to progressive, mild-moderate, asymptomatic valve disease; stage C disease is severe in nature but clinically asymptomatic; stage C1 characterizes asymptomatic patients with severe valve disease but compensated ventricular function; stage C2 refers to asymptomatic, severe disease with ventricular decompensation; stage D refers to severe, symptomatic valve disease. With aortic stenosis, stage D1 refers to symptomatic patients with severe aortic stenosis and a high valve gradient (>40 mmHg mean gradient); stage D2 comprises patients with symptomatic, severe, low-flow, low-gradient aortic stenosis and low left ventricular ejection fraction (LVEF); and stage D3 characterizes patients with symptomatic, severe, low-flow, low-gradient aortic stenosis and preserved LVEF (paradoxical, low-flow, low-gradient severe aortic stenosis). Patients with symptomatic severe AS (left side of the diagram, jet velocity ≥4m/s) should be referred for AVR (SAVR or TAVI). Asymptomatic patients with severe AS (jet velocity ≥4m/s) should be referred for AVR (SAVR or TAVI) for LVEF <50% or when other cardiac surgery is needed (e.g., aneurysm repair). There are several findings for which referral for AVR would be reasonable related to results of exercise testing, the presence of a jet velocity >5 m/s, or elevated B-type natriuretic peptide (BNP), provided the patient is considered low risk for complications related to AVR. AS, aortic stenosis; AVA, aortic valve area; AVR, aortic valve replacement; BP, blood pressure; DSE, dobutamine stress echocardiography; EF, ejection fraction; ETT, exercise treadmill test; ΔPmean, mean pressure gradient; SAVR, surgical AVR; TAVI, transcatheter aortic valve implantation; Vmax, maximum velocity. (Reproduced with permission from CM Otto et al: 2020 AHA/ACC Guideline for management of patients with valvular heart disease: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Circulation 143(5):e72, 2021.) inhibitors of the renin-angiotensin-aldosterone system slow the rate of progression of AS. The use of statin medications should be driven by considerations regarding primary and secondary pre vention of atherosclerotic cardiovascular disease (ASCVD) events. Studies with agents targeted to Lp(a) are ongoing. The need for endocarditis prophylaxis is restricted to AS patients with a prior history of endocarditis. SURGICAL TREATMENT Asymptomatic patients with calcific AS and severe obstruction should be followed carefully for the development of symptoms and for evidence of deteriorating LV function on serial echocardiogra phy. Operation is indicated in patients with severe AS (valve area

CHAPTER 272 No AS symptoms Aortic Stenosis AS stage B (Vmax 3–3.9 m/s) AS stage C (Vmax ≥4 m/s) Other cardiac surgery Other cardiac surgery ETT with ↓BP or ↓ex. capacity Vmax ≥5 m/s or BNP >3x normal or Rapid disease progression ↓ EF to <60% on 3 serial studies Low surgical risk <1 cm2 or 0.6 cm2/m2 body surface area) who are symptomatic, those who exhibit LV systolic dysfunction (EF <50%), and those with AS due to BAV disease and an aneurysmal root or ascending aorta (maximal dimension >5.5 cm). Operation for aneurysm disease is recommended

at smaller aortic diameters (4.5–5.0 cm) for patients with a family history of an aortic catastrophe and for patients who exhibit rapid aneurysm growth (>0.5 cm/year). Patients with asymptomatic moder ate or severe AS who are referred for coronary artery bypass grafting surgery should also have AVR. The majority (~80%) of patients with symptomatic severe AS referred for surgery are considered low risk for perioperative death or major complication. Operative risk increases as a function of age, comorbidities, and the need for concomitant aortic or other heart valve surgery or coronary artery bypass grafting. A 2023

analysis from the STS Adult Cardiac Surgery Database reported a 5-year survival rate of 95% following isolated surgical AVR (SAVR) in low-risk AS patients of mean age 74 years. The indications for SAVR in the asymptomatic patient have been the subject of intense debate, as surgical outcomes in selected patients have continued to improve. Relative indications for which surgery is reasonable include an abnormal response to treadmill exercise; rapid progres sion of AS, especially when urgent access to medical care might be compromised; very severe AS, defined by an aortic valve jet velocity

> 5 m/s or mean gradient >60 mmHg; excessive LV hypertrophy in the absence of systemic hypertension; and a brain natriuretic pep tide level >3 times the upper reference limit, with low surgical risk. Exercise testing can be safely performed in asymptomatic patients, as many as one-third of whom will show signs of functional impair ment. In a small randomized controlled trial (RCT) of early surgery versus conservative care for asymptomatic patients with very severe AS (defined by a transaortic valve jet velocity ≥4.5 m/s, mean gradi ent ≥50 mmHg, or aortic valve area ≤0.75 cm2), the rate of opera tive death or death from cardiovascular causes during follow-up was reduced with early surgery. In the conservative care group, the cumulative incidence of sudden death was 4% at 4 years and 14% at 8 years. In another randomized trial of early surgery versus conser vative care for asymptomatic patients with lesser degrees of AS (jet velocity ≥4 m/s, mean gradient ≥40 mmHg, aortic valve areas ≤1.0 cm2) and normal LV systolic function, early surgery resulted in a significant reduction in a composite endpoint of death, MI, stroke, and heart failure hospitalization.

PART 6 Disorders of the Cardiovascular System Operation should be carried out promptly (1–3 months) after symptom onset. Clinical decision-making is straightforward for patients with normal-flow (>35 mL/m2), high-gradient (≥40 mmHg) severe AS. In patients with low-flow, low-gradient severe AS with reduced LVEF, perioperative mortality rates are high (15–20%), and evidence of LV dysfunction usually persists even after a technically successful operation. Long-term postoperative sur vival correlates with preoperative LV function. Nonetheless, in view of the even worse prognosis of such patients when they are treated medically, there is usually little choice but to advise valve replacement, especially in patients in whom flow reserve can be demonstrated by dobutamine stress echocardiography (defined by a ≥20% increase in stroke volume after dobutamine challenge). Patients in this high surgical risk group are treated with TAVI whenever feasible (see below), but robust data from RCTs in this subpopulation of severe AS patients are lacking. The management of patients with low-flow, low-gradient severe AS with normal LVEF is also

challenging. Outcomes are improved with surgery or TAVI compared with conservative care for symptomatic patients with this type of “paradoxical” low-flow AS, but more research is needed to guide therapeutic decision-making for individual patients. In patients in whom severe AS and CAD coexist, relief of the AS and revascularization may sometimes result in striking clinical and hemodynamic improvement. Because many patients with calcific AS are elderly, particular attention must be directed to the adequacy of hepatic, renal, and pulmonary function before AVR is recommended. Age alone is not a contraindication to SAVR for AS. The perioperative mortality rate depends to a substantial extent on the patient’s preoperative clinical and hemodynamic state. Assessment of frailty is a criti cal component of preprocedural evaluation. Treatment decisions for AS patients who are not at low operative risk are made by a multidisciplinary heart team with representation from general car diology, interventional cardiology, multimodality imaging, cardiac surgery, and other subspecialties as needed, including geriatrics. The 8-year survival rate of older adult (mean age 74), low surgical risk patients following isolated SAVR is 85–90%. Recommenda tions regarding the type of valve prosthesis (biological or mechani cal) must weigh the trade-offs between limited bioprosthetic valve durability and the risks of thromboembolism and bleeding with a mechanical valve and are heavily influenced by patient age, expected longevity, and individual preferences. Bioprostheses are

generally favored for patients age >65 years. Shared decisionmaking with younger patients must be individualized, although increasing numbers of patients age <65 now opt for a biological valve replacement. Approximately 10–20% of bioprosthetic valves evidence primary valve failure by 15 years, requiring re-replace ment (or valve-in-valve TAVI, see below), and an approximately equal percentage of patients with mechanical prostheses develop hemorrhagic complications as a consequence of treatment with vitamin K antagonists. In a large observational study of patients who underwent SAVR in California between 1996 and 2013, receipt of a biological versus a mechanical prosthesis in patients <55 years old was associated with an excess hazard of death over 15 years of follow-up. Homograft AVR is usually reserved for patients with aortic valve endocarditis. The Ross procedure involves replacement of the diseased aortic valve with the autologous pulmonic valve and implantation of a homograft in the native pulmonic position. It is a technically complex procedure that may be considered in selected young or middle-aged adult patients when surgical and institutional exper tise are available. Late postoperative complications include aortic root dilation, AR, and pulmonary homograft stenosis. PERCUTANEOUS AORTIC BALLOON VALVULOPLASTY This procedure is preferable to operation in many children and young adults with congenital, noncalcific AS (Chap. 280). It is not recommended as definitive therapy in adults with severe calcific AS because of a very high restenosis rate (80% within 1 year) and the risk of procedural complications, although on occasion, it has been used successfully as a bridge to operation or TAVI in patients with severe LV dysfunction and shock. It is performed routinely as part of the TAVI procedure (see below). TRANSCATHETER AORTIC VALVE IMPLANTATION TAVI surpassed SAVR for treatment of isolated AS in the United States in 2016 and is now available to symptomatic patients across the entire surgical risk spectrum (prohibitive, high, intermediate, and low) on the basis of the favorable results observed in a series of landmark RCTs reported over the past decade. The results of a randomized trial of TAVI versus conventional care in asymp tomatic AS patients will be released around 2024–2025. TAVI is most commonly performed using one of two systems, a balloonexpandable valve (BEV) or a self-expanding valve (SEV), both of which incorporate a pericardial bioprosthesis (Fig. 272-5A, B). TAVI is most frequently undertaken via the transfemoral route, although trans-LV apical, subclavian, carotid, and ascending aor tic routes have

been used. Nonfemoral access is associated with higher complication rates. Aortic balloon valvuloplasty under rapid RV (or LV) pacing is performed as a first step to create an orifice of sufficient size for the prosthesis. Procedural success rates exceed 95% in appropriately selected patients. Among low surgical risk patients with symptomatic severe AS, random ized trials with follow-up through 4–5 years have demonstrated similar valve performance and clinical outcomes for SAVR versus TAVI using either a BEV or SEV platform (Fig. 272-6). Outcomes achieved with TAVI technology have been very favorable and have allowed the extension of AVR to groups of patients previ ously considered poor candidates for conventional surgery. Nev ertheless, some prohibitive or high surgical risk patients are not candidates for this procedure because their comorbidity profile, frailty, and expected longevity would make its undertaking inap propriate. The heart team is specifically charged with making challenging decisions of this nature. The use of these devices for treatment of patients with structural deterioration of biopros thetic aortic valves (valve-in-valve TAVI), as an alternative to reoperative valve replacement, has increased sharply over the past 5 years. The technology has also been increasingly applied to selected BAV patients despite the fact that patients with this anatomy were excluded from the landmark RCTs.

B V N A B FIGURE 272-5 Balloon-expandable (A) and self-expanding (B) valves for transcatheter aortic valve replacement (TAVR). B, inflated balloon; N, nose cone; V, valve. (Part A, courtesy of Edwards Lifesciences, Irvine, CA; with permission. NovaFlex+ is a trademark of Edwards Lifesciences Corporation. Part B, © Medtronic, Inc. 2015. Medtronic CoreValve Transcatheter Aortic Valve. CoreValve is a registered trademark of Medtronic, Inc.) Compared with SAVR, transfemoral TAVI results in fewer peri procedural deaths and confers lower risks of strokes, major bleed ing, and AF. Hospital lengths of stay are significantly shorter and return to normal activity more rapid with TAVI. Rates of perma nent pacemaker use, perivalvular AR, bioprosthetic leaflet throm bosis, and vascular complications are lower with SAVR. The choice between TAVI versus SAVR for patients with trileaflet AS who

HR = 0.74 (95% CI 0.54–1.00) Log-rank p = 0.05 25% 4 Years SE TAVR SAVR Δ–3.4% All-cause mortality or disabling stroke 2 Years 3 Years 20% CHAPTER 272 Δ–2.0% Δ–2.9% 10.3% 14.1% 15% 10% 1 Year Δ–1.8% 10.7% 4.3% 6.3% 2.5% 4.3% 7.4% 5% 0%

Aortic Stenosis

Months since procedure

SE TAVR SAVR

FIGURE 272-6 Four-year cumulative incidence of all-cause mortality or disabling stroke for low surgical risk aortic stenosis patients assigned to self-expanding transcatheter aortic valve implantation (SE-TAVR; n = 730) or surgical aortic valve replacement (SAVR; n = 684). In this study, TAVR was noninferior to SAVR and marginally superior to SAVR for the combined endpoint. (Reproduced with permission from JK Forrest et al: 4-year outcomes of patients with aortic stenosis in the EVOLUT low risk trial. J Am Coll Cardiol 82:2163, 2023.) prefer a biological prosthesis rests on several clinical, imag ing, and technical considerations (Fig. 272-7 and Table 272-3). Because there are scant RCT data on TAVI outcomes in patients <65 years, SAVR is recommended in this age group. Aortic valve/ root anatomy, as well as the extent, severity, and distribution of calcium, and

the distance of the coronary arteries from the plane of the annulus, may dictate a surgical approach, as could the need to perform a concomitant procedure such as ascending aortic replacement. Lastly, inability to achieve transfemoral access is a relative impediment to TAVI given the higher complication rates observed when this procedure is undertaken from other vascular access sites. Class 1 Shared decision making Class 2a Bioprosthetic Valve Class 2b Indication for AVR and anatomy suitable for TF TAVI? No Yes Age < 65 Age 65 to 80 Age >80 SAVR (1) SAVR (1) TF TAVI (1) TF TAVI (1) SAVR (2a) FIGURE 272-7 Suggested decision-making algorithm for the elective choice of transcatheter aortic valve implantation (TAVI) versus surgical aortic valve replacement (SAVR) for aortic stenosis patients with an indication for valve intervention. The pathway emphasizes the premium placed on transfemoral (TF) TAVI access and the age-related differences in recommendations. Patients younger than age 65 are recommended to undergo SAVR given the paucity of prospective randomized data on intermediate- and long-term TAVI outcomes for individuals younger than age 70. AVR, aortic valve replacement. (Reproduced and abridged with permission from CM Otto et al: 2020 AHA/ACC Guideline for management of patients with valvular heart disease: A report of the American College of Cardiology/ American Heart Association Task Force on Practice Guidelines. Circulation 143:e72, 2021.)

TABLE 272-3 Factors Favoring SAVR, TAVI, or Palliative Care in Patients with Aortic Stenosis FAVORS SAVR FAVORS TAVI FAVORS PALLIATION Age/life expectancya Younger age/longer life expectancy Older age/fewer expected remaining years of life Valve anatomy Bicuspid aortic valve Subaortic (LVOT) calcification Rheumatic valve disease Small or large aortic annulusb PART 6 Disorders of the Cardiovascular System Prosthetic valve preference Mechanical or surgical bioprosthetic valve preferred Concern for patient-prosthesis mismatch (annular enlargement might be considered) Concurrent cardiac conditions Aortic dilationc Severe primary MR Severe CAD requiring bypass grafting Septal hypertrophy requiring myectomy Atrial fibrillation Noncardiac conditions Severe lung, liver, or renal disease Mobility issues (high risk for sternotomy) Frailty Not frail or few frailty measures Frailty likely to improve after TAVI Severe frailty unlikely to improve after TAVI Estimated risk of SAVR or TAVI SAVR risk low TAVI risk high Procedure-specific impediments Valve anatomy, annular size, or low coronary ostial height precludes TAVI Vascular access does not allow transfemoral TAVI Goals of care and patient preferences and values Less uncertainty about valve durability Avoid repeat intervention Lower risk of permanent pacer Life prolongation Symptom relief Improved long-term exercise capacity and QOL Avoid vascular complications Accepts longer hospital stay, pain in recovery period aData on bioprosthetic valve durability are more robust for SAVR valves than for TAVI valves. Mechanical valves are very durable but require lifelong anticoagulation. Choice of prosthesis is a shared decision-making process accounting for individual patient values and preferences. bSurgical root enlargement can be performed at time of SAVR to allow a use of a larger prosthesis and reduce the occurrence of prosthesis-patient mismatch. cAortic root or ascending aortic enlargement may require surgical correction at time of SAVR. Abbreviations: AS, aortic stenosis; CAD, coronary artery disease; LV, left ventricular; LVOT, left ventricular outflow tract; MR, mitral regurgitation; QOL, quality of life; SAVR, surgical aortic valve replacement; TAVI, transcatheter aortic valve implantation. Source: Reproduced with permission from CR Burke et al: Goals of care in patients with severe aortic stenosis. Eur Heart J 41:929, 2020. ■ ■FURTHER READING Banovic M et al: Aortic valve replacement versus conservative treat ment in asymptomatic severe aortic stenosis: The AVATAR trial. Circulation 145:648, 2022. Carapetis JR et al: Acute rheumatic fever and rheumatic heart disease. Nat Rev Dis Primers 2:15084, 2016. Forrest JK et al: 4-year outcomes of patients with

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Limited life expectancy Calcific trileaflet AS Bioprosthetic valve preferred Favorable ratio of life expectancy to valve durability TAVI provides larger valve area than same-sized SAVR Severe calcification of the ascending aorta (“porcelain” aorta) Irreversible severe LV systolic dysfunction Severe MR due to annular calcification Symptoms likely due to noncardiac conditions Severe dementia Moderate to severe involvement of 2 or more other organ systems TAVI risk low to medium SAVR risk high to prohibitive Prohibitive SAVR risk (>15%) or post-TAVI life expectancy <1 year Previous cardiac surgery with at-risk coronary grafts Previous chest irradiation Valve anatomy, annular size, or coronary ostial height precludes TAVI Vascular access does not allow transfemoral TAVI Accepts uncertainty about valve durability and possible repeat intervention Higher risk of permanent pacer Life prolongation Symptom relief Improved exercise capacity and QOL Prefers shorter hospital stay, less postprocedure pain Life prolongation not an important goal Avoid futile or unnecessary diagnostic or therapeutic procedures Avoid procedural stroke risk Avoid possibility of cardiac pacer of Cardiology/American Heart Association Task Force on Practice Guidelines. Circulation 143:e72, 2021. Siontis GCM et al: Transcatheter aortic valve implantation versus surgical aortic valve replacement for treatment of symptomatic severe aortic stenosis: An updated meta-analysis. Eur Heart J 40:3143, 2019. Thourani VH: Survival after surgical aortic valve replacement in low-risk patients: A contemporary trial benchmark. Ann Thor Surg 117:106, 2024. Tsao CW et al: Heart disease and stroke statistics–2023 update. A report from the American Heart Association. Circulation 147:e93, 2023. Watkins DA et al: Global, regional, and national burden of rheumatic heart disease, 1990-2015. N Engl J Med 377:713, 2017. Zühlke L et al: Clinical outcomes in 3343 children and adults with rheumatic heart disease from 14 low- and middle-income countries: Two-year follow-up of the global Rheumatic Heart Disease Registry (the REMEDY Study). Circulation 134:1456, 2016.

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