CME CREDIT *EDUCATIONAL OBJECTIVE:* Readers will know when to refer patients for consideration of surgical or transcatheter aortic valve replacement

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Aortic stenosis: Who should undergo surgery, transcatheter valve replacement?

ABSTRACT

Aortic stenosis, the most common valvular disease in the Western world, affects mainly people over age 60. It is characterized by years to decades of slow progression followed by rapid clinical deterioration and a high death rate once symptoms develop. Drug therapy for it remains ineffective, and surgical aortic valve replacement is the only effective long-term treatment. We discuss the indications for this surgery, with an emphasis on controversial conditions in which the indications are less well defined.

KEY POINTS

The management of severe but asymptomatic aortic stenosis is challenging. An abnormal response to exercise stress testing and elevated biomarkers may identify a higher-risk group that might benefit from closer follow-up and earlier surgery.

Even patients with impaired left ventricular function and advanced disease can have a good outcome from surgery.

Dobutamine infusion can help ascertain which patients with low-flow, low-gradient aortic valve stenosis have true severe stenosis (as opposed to pseudostenosis) and are most likely to benefit from aortic valve replacement.

Transcatheter aortic valve implantation will soon become the procedure of choice for patients at high risk for whom surgery is not feasible, and it may be an alternative to surgery in other patients at high risk even if they can undergo surgery.

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For some patients with aortic stenosis, the choice of management is simple; for others it is less so. Patients who have severe, symptomatic stenosis and who have low surgical risk should undergo aortic valve replacement. But if the stenosis is severe but asymptomatic, or if the patient is at higher surgical risk, or if there seems to be a mismatch in the hemodynamic variables, the situation is more complicated.

See related editorial, page 483

Fortunately, we have evidence and guidelines to go on. In this paper we review the indications for surgical and transcatheter aortic valve replacement, focusing on the areas of less certainty.

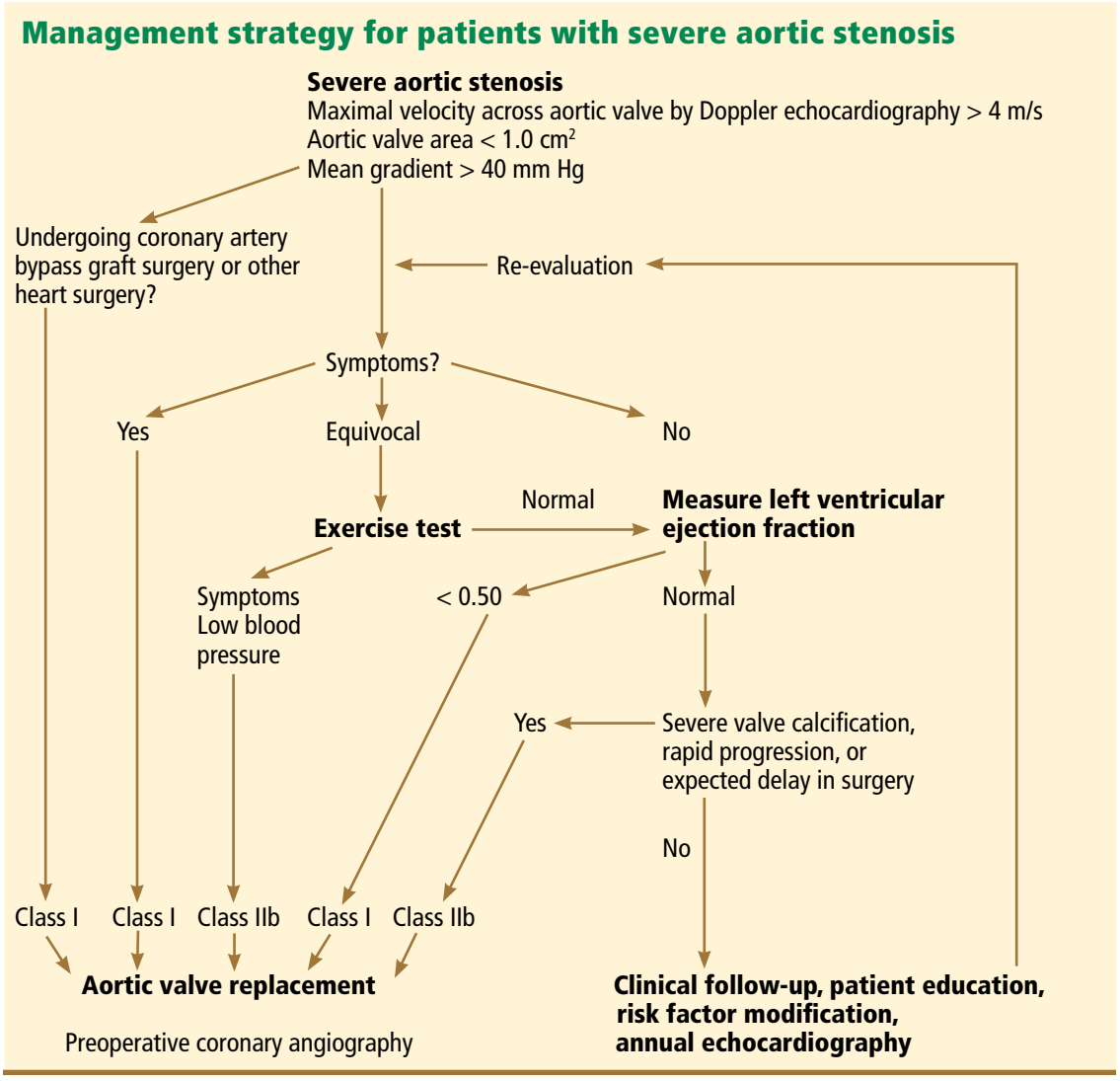
AN INDOLENT DISEASE, UNTIL IT ISN'T

Aortic stenosis is the most common valvular disease and the third most prevalent form of cardiovascular disease in the Western world, after hypertension and coronary artery disease. It is largely a disease of the elderly; its prevalence increases with age, and it is present in 2% to 7% of patients over age 65.[1,2]

At first, its course is indolent, as it progresses slowly over years to decades. However, this is followed by rapid clinical deterioration and a high death rate after symptoms develop.

SURGICAL AORTIC VALVE REPLACEMENT FOR SEVERE SYMPTOMATIC STENOSIS

Classic symptoms of aortic stenosis include angina, heart failure, and syncope. Once symptoms



The onset of symptoms confers a poor prognosis

FIGURE 1. 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 discordance between clinical findings and echocardiography.

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appear, patients with severe aortic stenosis should be promptly referred for surgical aortic valve replacement, as survival is poor unless outflow obstruction is relieved (FIGURE 1). The onset of symptoms confers a poor prognosis: patients die within an average of 5 years after the onset of angina, 3 years after the onset of syncope, and 2 years after the onset of heart failure symptoms. The overall mortality rate is 75% at 3 years without surgery.[3,4] Furthermore, 8% to 34% of patients with symptoms die suddenly.

Advances in prosthetic-valve design, cardiopulmonary bypass, surgical technique, and anesthesia have steadily improved the outcomes of aortic valve surgery. An analysis of the Society of Thoracic Surgeons (STS) database in 2006 showed that during the previous decade the death rate during isolated aortic valve replace-

ment decreased from 3.4% to 2.6%. For patients under age 70 at the time of surgery, the rate of death was 1.3%, and in those ages 80 to 85, the 30-day mortality rate was less than 5%.[5]

Patients who survive surgery enjoy a near-normal life expectancy: 99% survive at least 5 years, 85% at least 10 years, and 82% at least 15 years.[6,7] Nearly all have improvement in their ejection fraction and heart failure symptoms, and those who had more advanced symptoms before surgery enjoy the most benefit afterward.[8,9]

Recommendation. Surgical valve replacement for symptomatic severe aortic stenosis receives a class I recommendation, level of evidence B, in the current guidelines from the American College of Cardiology (ACC) and the American Heart Association (AHA).[10,11] (See TABLE 1 for an explanation of the classes of recommendations and levels of evidence.)

TWO RISK-ASSESSMENT SCORES

There are two widely used scores for assessing the risk of aortic valve replacement: the European System for Cardiac Operative Risk Evaluation (EuroSCORE) and the STS score. Each has limitations.

The EuroSCORE was developed to predict the risk of dying in the hospital after adult cardiac surgery. It has been shown to predict the short-term and the long-term risk of death after heart valve surgery.[12] Unfortunately, it overestimates the dangers of isolated aortic valve replacement in the patients at highest risk.[13,14]

The STS score, a logistic model, reflects more closely the operative and 30-day mortality rates for the patients at highest risk undergoing surgical aortic valve replacement.[15,16] It was used to assess patients for surgical or transcatheter aortic valve replacement in the Placement of Aortic Transcatheter Valves (PARTNER) trial.[17]

These risk scores, though not perfect, are helpful as part of an overall estimation of risk that includes functional status, cardiac function, and comorbidities.

OTHER INDICATIONS FOR SURGICAL AORTIC VALVE REPLACEMENT

For patients with severe but asymptomatic aortic stenosis, surgical referral is standard practice in several circumstances.

TABLE 1

Classes of recommendations and levels of evidence used in ACC/AHA guidelines

Classes

Class I: Conditions for which there is evidence for or general agreement that the procedure or treatment is beneficial, useful, and effective

Class II: Conditions for which there is conflicting evidence or a divergence of opinion about the usefulness or efficacy of a procedure or treatment

Class IIa: Weight of evidence or opinion is in favor of usefulness or efficacy

Class IIb: Usefulness or efficacy is less well established by evidence or opinion

Class III: Conditions for which there is evidence or general agreement that the procedure or treatment is not useful or effective and in some cases may be harmful

Level of evidence

A: Data derived from multiple randomized clinical trials

B: Data derived from a single randomized trial or nonrandomized studies

C: Only consensus opinion of experts, case studies, or standard-of-care

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Asymptomatic severe aortic stenosis with a low ejection fraction

Early studies found significant differences in survival beginning as early as 3 years after valve replacement between those whose preoperative ejection fraction was greater than 50% and those with a lower ejection fraction.[4] Delaying surgery in these patients may lead to irreversible left ventricular dysfunction and worse survival.

Recommendation. The AHA and the ACC recommend surgical aortic valve replacement for patients who have no symptoms and whose left ventricular ejection fraction is less than 50% (class I indication, level of evidence C).[10,11]

Asymptomatic severe aortic stenosis in patients undergoing other cardiac surgery

Recommendation. Even if it is causing no symptoms, a severely stenotic aortic valve ought to be replaced if the ejection fraction is greater than 50% and the patient is undergoing another type of heart surgery, such as coronary artery bypass grafting, aortic surgery, or surgery on other heart valves (class I indication, level of evidence B).[10,11]

Asymptomatic moderate aortic stenosis in patients undergoing other cardiac surgery

When patients with a mildly or moderately stenotic aortic valve undergo other types of cardiac surgery, the decision to replace the valve is more difficult. Clinicians have to consider the increase in risk caused by adding aortic valve replacement to the planned surgery compared with the future likelihood of aortic stenosis progressing to a severe symptomatic state and eventually requiring a second cardiac surgery.

We have no evidence from a large prospective randomized controlled trial regarding prophylactic valve replacement at the time of coronary bypass surgery. However, a review of outcomes from the STS database between 1995 and 2000 found that patients under age 70 with a peak aortic gradient greater than "about 28 mm Hg" (correlating with a moderate degree of stenosis) benefited from prophylactic valve replacement at the time of coronary artery bypass surgery.[18]

Patients who survive surgery enjoy a near-normal life expectancy

These conclusions were supported by a subsequent retrospective analysis that found a significant survival advantage at 8 years in favor of prophylactic valve replacement at the time of bypass surgery for those with moderate (but not mild) aortic stenosis.[19]

Recommendation. The AHA and ACC give a class IIb endorsement, level of evidence B, for aortic valve replacement in patients with asymptomatic moderate aortic stenosis undergoing coronary bypass, valve, or aortic surgery.[10,11]

SEVERE ASYMPTOMATIC STENOSIS: WHICH TESTS HELP IN DECIDING?

A patient without symptoms presents a greater challenge than one with symptoms.

If surgery is deferred, the prognosis is usually excellent in such patients. Pellikka et al[20] found that patients with severe asymptomatic aortic stenosis who did not undergo surgery had a rate of sudden cardiac death of about 1% per year of follow-up. However, physicians worry about missing the rapid development of symptoms of aortic stenosis in patients who previously had none. Pallikka et al also found that, at 5 years, only 20% of patients had not undergone aortic valve replacement or had not died of cardiovascular causes.[20]

Many researchers advocate surgical aortic valve replacement for severe asymptomatic aortic stenosis. However, the operative risk is 3% overall and has to be weighed against the 1%-per-year risk of death in patients who do not undergo surgery. Therefore, we need a way to identify a subgroup of patients without symptoms who are at higher risk.

Exercise stress testing

Some patients might subconsciously adapt to aortic stenosis by reducing their physical activity. In these "asymptomatic" patients, exercise stress testing can uncover symptoms in around 40%.[21]

In a group of people with severe asymptomatic aortic stenosis, a positive treadmill test (defined as an abnormal blood pressure response, ST segment changes, symptoms such as limiting dyspnea, chest discomfort, or dizziness on a modified Bruce protocol, or complex ventricular arrhythmias) strongly predicted the onset of symptoms or the need for surgery. At 24 months, only 19% of those who had had a positive exercise test result remained alive, symptom-free, and without valve replacement, compared with 85% of those who had had a negative test result.[22]

Subsequent study found that symptoms with exercise were the strongest predictor of the onset of symptoms of aortic stenosis, especially among patients under age 70, in whom the symptoms of fatigue and breathlessness are more specific than in the elderly.[23]

Recommendation. Exercise testing is recommended in patients with severe asymptomatic aortic stenosis (class IIa indication, level of evidence B) as a means of identifying those who are likely to develop symptoms or who might benefit from surgery. Surgery for those

who have an abnormal exercise stress response receives a class IIb, level of evidence C recommendation from the ACC/AHA and a class IC from the European Society of Cardiology.[24,25]

Exercise stress echocardiography to measure change in transvalvular gradient

Emerging data suggest that exercise stress echocardiography may provide incremental prognostic information in patients with severe asymptomatic aortic stenosis. In fact, two studies showed that an exercise-induced increase in the transvalvular gradient of more than 20 mm Hg[26] or 18 mm Hg[27] predicts future cardiac events. This increase reflects fixed valve stenosis with limited valve compliance.

Other echocardiographic variables

Additional data have shown that severe aortic stenosis (valve area < 0.6 cm^2), aortic velocity greater than 4.0 m/s, and severe calcification confer a higher risk of developing symptoms.[28,29]

Recommendation. The ACC and AHA say that surgical aortic valve replacement may be considered in patients without symptoms who have a high likelihood of rapid progression of aortic stenosis (ie, who are older or have severe calcification or coronary artery disease) or if surgery might be delayed at the time of symptom onset (class IIb, level of evidence C).

Aortic valve replacement can also be considered for extremely severe aortic stenosis (valve area < 0.6 cm^2), mean gradient > 60 mm Hg, and velocity > 5.0 m/s if the operative mortality rate is 1.0% or less (class IIb, level of evidence C).

Brain natriuretic peptide levels

Measuring the brain natriuretic peptide (BNP) level may help if symptoms are unclear; higher levels suggest cardiac decompensation.[28]

One study showed that BNP levels are higher in patients with symptomatic aortic stenosis than in those with asymptomatic severe disease, and correlate with symptom severity.[30] In addition, in two other studies, higher BNP and N-terminal BNP levels were shown to predict disease progression, symptom onset, and poorer event-free survival.[31,32]

In severe asymptomatic aortic stenosis, natriuretic peptides may provide important prognostic information beyond clinical and echocardiographic evaluation. Furthermore, in a recent study, Monin et al[33] proposed a risk score that integrates peak aortic jet velocity, BNP level, and sex (women being at higher risk) in predicting who would benefit from early surgery in patients with severe asymptomatic aortic stenosis.[33]

SPECIAL CONSIDERATIONS

Low-output, low-gradient aortic stenosis: True severe stenosis vs pseudostenosis

Patients with a low ejection fraction (< 50%) and a high mean transvalvular gradient (> 30 or 40 mm Hg) pose no therapeutic dilemma. They have true afterload mismatch and improve markedly with surgery.[34] However, patients with an even lower ejection fraction (< 35% or 40%) and a low mean transvalvular gradient (< 30 or 40 mm Hg) pose more of a problem.

It is hard to tell if these patients have true severe aortic stenosis or pseudostenosis due to primary myocardial dysfunction. In pseudostenosis, the aortic valves are moderately diseased, and leaflet opening is reduced by a failing ventricle. When cardiac output is low, the formulae used to calculate the aortic valve area become less accurate, so that patients with cardiomyopathy who have only mild or moderate aortic stenosis may appear to have severe stenosis.

Some patients might subconsciously adapt to aortic stenosis by reducing their physical activity

Patients with pseudostenosis have a high risk of dying during surgical aortic valve replacement, approaching 50%, and benefit more from evidence-based heart failure management.[35,36] In patients with true stenosis, ventricular dysfunction is mainly a result of severe stenosis and should improve after aortic valve replacement.

Dobutamine stress echocardiography can be used in patients with low-flow, low-gradient aortic stenosis to distinguish true severe stenosis from pseudostenosis. Dobutamine, an inotropic drug, increases the stroke volume so that patients with true severe aortic stenosis increase their transvalvular gradient and velocity with no or minimal change in the valve area. Conversely, in patients with pseudostenosis, the increase in stroke volume will

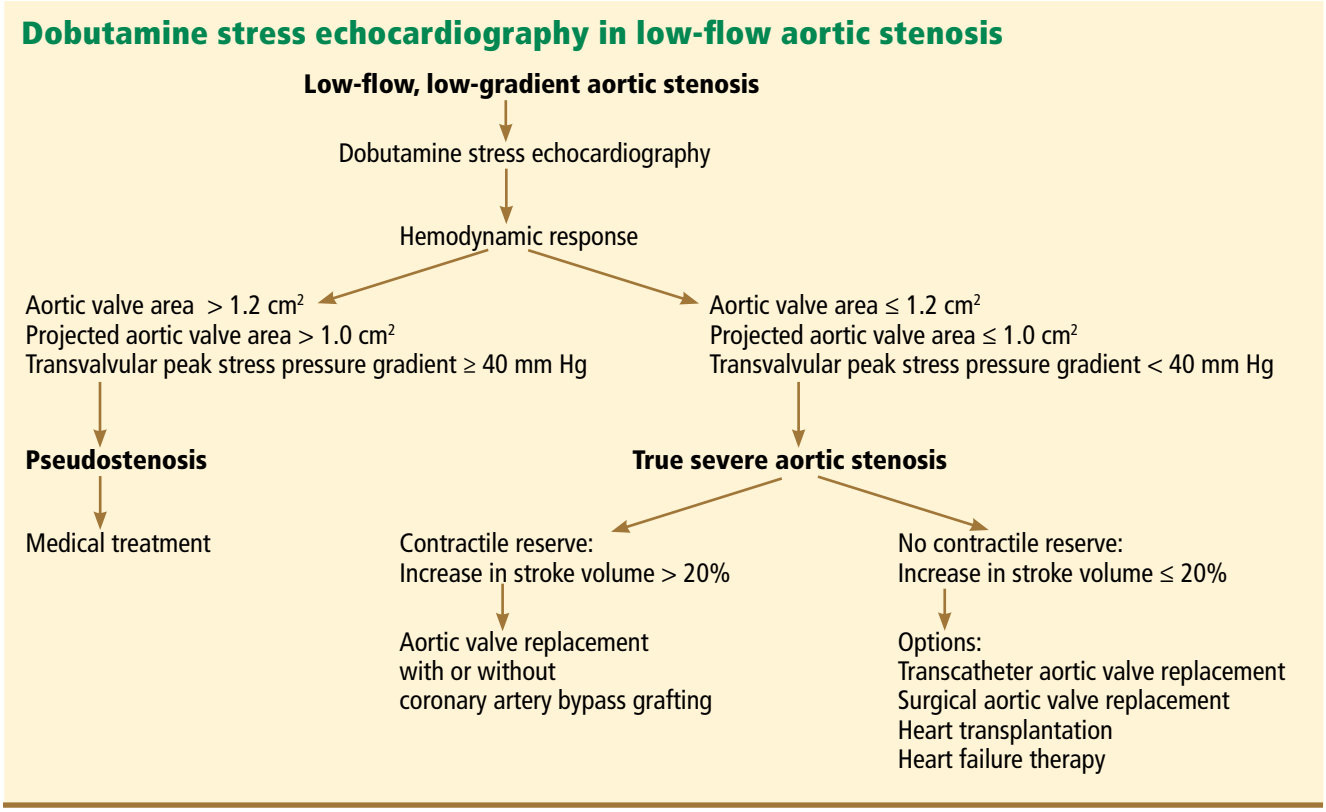

FIGURE 2. How dobutamine stress echocardiography can help in decision-making in patients with low-flow aortic stenosis. Contractile reserve is a good prognostic sign, and the subset of patients who have it should be considered for aortic valve replacement. Management decisions are less well-defined when contractile reserve is absent. Contractile reserve is defined as an increase in stroke volume of more than 20% on a low-dose protocol of dobutamine (ie, up to 20 µg/kg/min).[40,41] When contractile reserve is present, patients with true severe aortic stenosis will show an increase in the transvalvular pressure gradient of ≥ 30 to 40 mm Hg with a low calculated aortic valve area , ie ≤ 1.2 cm². One can also determine the projected aortic valve area at a standardized normal flow rate (projected aortic valve area) to make the distinction between true severe and pseudosevere aortic stenosis when there are discordances in the findings of peak stress aortic valve area and gradient. A projected aortic valve area ≤ 1.0 cm² indicates true severe stenosis.[40,41]

open the aortic valve further and cause no or minimal increase in transvalvular gradient and velocity, but will increase the calculated valve area, confirming that aortic stenosis only is mild to moderate.[37]

Patients with low-flow, low-gradient aortic stenosis are at higher risk during surgical aortic valve replacement. Many studies have reported a 30-day mortality rate between 9% and 18%, although risks vary considerably within this population.[38,39]

Contractile reserve. Dobutamine stress echocardiography has also been used to identify patients with severe aortic stenosis who can increase their ejection fraction and stroke volume (**FIGURE 2**).[40,41] These patients are said to have "contractile reserve" and do better with surgery than those who lack adequate contractile reserve. Contractile reserve is defined as an increase of more than 20% in stroke volume during low-dose dobutamine infusion.[42,43] In one small nonrandomized study, patients with contractile reserve had a 5% mortality rate at 30 days, compared with 32% in patients with no contractile reserve.[44,45]

In fact, patients with no contractile reserve have a high operative mortality rate during aortic valve replacement, but those who survive the operation have improvements in symptoms, functional class, and ejection fraction similar to those in patients who do have contractile reserve.[46]

On the other hand, if patients with no contractile reserve are treated conservatively, they have a much worse prognosis than those managed surgically.[47] While it is true that patients without contractile reserve did not have a statistically significant difference in mortality rates with aortic valve replacement (P = .07) in a study by Monin et al,[44] the difference was staggering between the group who underwent aortic valve replacement and the group who received medical treatment alone (hazard ratio = 0.47, 95% confidence interval 0.31–1.05, P = .07). The difference in the mortality rates may not have reached statistical significance because of the study's small sample size.

A few years later, the same group published a similar paper with a larger study sample, focusing on patients with no contractile reserve. Using 42 propensity-matched patients, they found a statistically significantly higher 5-year survival rate in patients with no contractile reserve who underwent aortic valve replacement than in similar patients who received medical management (65% ± 11% vs 11 ± 7%, P = .019).[47]

Hence, surgery may be a better option than medical treatment for this select high-risk group despite the higher operative mortality risk. Transcatheter aortic valve implantation may also offer an interesting alternative to surgical aortic valve replacement in this particular subset of patients.[48]

Low-gradient 'severe' aortic stenosis with preserved ejection fraction or 'paradoxically low-flow aortic stenosis'

Low-gradient "severe" aortic stenosis with a preserved left ventricular ejection fraction is a recently recognized clinical entity in patients with severe aortic stenosis who present with a lower-than-expected transvalvular gradient on the basis of generally accepted values.[49] (A patient with severe aortic stenosis and preserved ejection fraction is expected to generate a mean transaortic gradient greater than 40 mm Hg.[24]) This situation remains incompletely understood but has been shown in retrospective studies to foretell a poor prognosis.[50–52]

This subgroup of patients has pronounced left ventricular concentric remodeling with a small left ventricular cavity, impaired left ventricular filling, and reduced systolic longitudinal myocardial shortening.[44]

Herrmann et al[53] provided more insight into the pathophysiology by showing that patients with this condition exhibit more pronounced myocardial fibrosis on myocardial biopsy and more pronounced late subendocardial enhancement on magnetic resonance imaging. These patients also displayed a significant decrease in mitral ring displacement and systolic strain. These abnormalities result in a low stroke volume despite a preserved ejection fraction and consequently a lower transvalvular gradient (< 40 mm Hg).

This disease pattern, in which the low gradient is interpreted as mild to moderate aortic stenosis, may lead to underestimation of stenosis severity and, thus, to inappropriate delay of aortic valve replacement.

However, other conditions can cause this hemodynamic situation with a lower-than-expected gradient. It can arise from a small left ventricle that correlates with a small body size, yielding a lower-than-normal stroke volume, measurement errors in determining stroke volume and valve area by Doppler echocardiography, systemic hypertension (which can influence estimation of the gradient by Doppler echocardiography), and inconsistency in the definition of severe aortic stenosis in the current guidelines relating to cutoffs of valve area in relation to those of jet velocity and gradient.[54]

Even when the patient has no symptoms, surgical referral for severe aortic stenosis is standard in several situations

This subgroup of patients seems to be at a more advanced stage and has a poorer prognosis if treated medically rather than surgically. When symptomatic, low-gradient severe aortic stenosis should be treated surgically, with one study showing excellent outcomes with aortic valve replacement.[50]

However, a recent study by Jander et al[55] showed that patients with low-gradient severe aortic stenosis and normal ejection fraction have outcomes similar to those in patients with moderate aortic stenosis, suggesting a strategy of medical therapy and close monitoring.[55] Of note, the subset of patients reported in this substudy of the Simvastatin and Ezetimibe in Aortic Stenosis (SEAS) trial did not really fit the pattern of low-gradient severe aortic stenosis described by Hachicha et al[50] and other groups.[51,56] These patients had aortic

valve areas in the severe range but mean transaortic gradients in the moderate range, and in light of the other echocardiographic findings in these patients, the area-gradient discordances were predominantly due to small body surface area and measurement errors. These patients indeed had near-normal left ventricular size, no left ventricular hypertrophy, and no evidence of concentric remodeling.

Finally, the findings of the study by Jander et al[55] are discordant with those of another substudy of the SEAS trial,[57] which reported that paradoxical low-flow aortic stenosis occurred in about 7% of the cohort (compared with 52% in the study by Jander et al[55]) and was associated with more pronounced concentric remodeling and more severe impairment of myocardial function.

Whether intervention in patients with low-gradient severe aortic stenosis and valve area less than 1.0 cm^2 improves outcomes remains to be confirmed and reproduced in future prospective studies.

Elderly patients

We need a way to identify a subgroup of patients without symptoms who are at higher risk

The risks of cardiac surgery increase with age. Older patients may be more deconditioned and have more comorbidities than younger patients, placing them at greater risk of a poor outcome.

Several retrospective studies of valve replacement in octogenarians have found that operative mortality rates range from 5.7% to 9% during isolated aortic valve replacement.[58–60] Note that, using the STS score, the operative mortality risk increases only from 1.2% in a 70-year-old man with no comorbidities to 1.8% in an 80-year-old man undergoing aortic valve replacement plus coronary artery bypass grafting.[61]

As in younger patients, valve replacement results in a significant survival benefit and symptomatic improvement. Yet up to 30% of patients with severe aortic stenosis are not referred for surgery because surgery is believed to be too risky.[62] The conditions most frequently cited by physicians when declining to refer patients for surgery include a low ejection fraction, advanced age, and advanced comorbidities. None of these is an absolute contraindication to surgery.

A recent retrospective study of 443 elderly patients (mean age 79.5) showed that those with left ventricular concentric remodeling, lower stroke volume, elevated left ventricular filling pressures, and mildly elevated pulmonary artery pressures have a very bad prognosis, with a mortality rate of 50.5% at 3.3 ± 2.7 years.[63]

Despite the higher operative mortality risk, these patients face a dismal prognosis when treated medically and should be referred to a cardiologist or cardiothoracic surgeon for an assessment of their operative risk and, potentially, for referral for catheter-based valve replacement.

Acutely ill patients

In critically ill patients with aortic stenosis and cardiogenic shock, the use of intravenous sodium nitroprusside increases cardiac output and decreases pulmonary artery wedge pressure, allowing patients to transition to surgery or vasodilator therapy. The mechanism seems to be an increase in myocardial contractility rather than a decrease in peripheral resistance. The reduction in filling pressure and concurrent increase in coronary blood flow relieves ischemia and subsequently enhances contractility.[64]

TRANSCATHETER AORTIC VALVE REPLACEMENT

Until recently, patients with severe aortic stenosis who were deemed to be at high surgical risk were referred for balloon valvuloplasty as a palliative option. The procedure consists of balloon inflation across the aortic valve to relieve the stenosis.

Most patients have improved symptoms and a decrease in pressure gradient immediately after the procedure, but the results are not durable, with a high restenosis rate within 6 to 12 months and no decrease in the mortality rate.[65] (There is some evidence that serial balloon dilation improves survival.[66])

The procedure has several limitations, including a risk of embolic stroke, myocardial infarction, and, sometimes, perforation of the left ventricle. It is only used in people who do not wish to have surgery or as a bridge to surgical aortic valve replacement in hemodynamically unstable patients.

Advances in transcatheter technologies have made nonsurgical valve replacement a reality that is increasingly available to a broader population of patients. The first percutaneous valve replacement in a human was performed in 2002.[67] Since then, multiple registries from centers around the world, especially in Europe, have shown that it can be performed in high-risk patients with outcomes very comparable to those of surgical aortic valve replacement as predicted by the STS score and EuroSCORE.[68,69] Procedural success rates have increased from around 80% in the initial experience to over 95% in the most current series.[70]

Results from randomized trials

The long-awaited PARTNER A and B trials have been published.

The PARTNER B trial[17] randomized patients with severe aortic stenosis who were not considered by the STS score to be suitable candidates for surgery to standard therapy (which included balloon valvoplasty in 84%) or transcatheter aortic valve replacement. There was a dramatic 20% absolute improvement in survival at 1 year with transcatheter replacement, with the survival curve continuing to diverge at 1 year. The rate of death from any cause was 30.7% with transcatheter aortic valve replacement vs 50.7% with standard therapy (hazard ratio with transcatheter replacement 0.55; $P < .001$).

The major concerns about transcatheter aortic valve replacement borne out in the study are procedural complications, namely stroke and vascular events. At 30 days, transcatheter replacement, as compared with standard therapy, was associated with a higher incidence of major stroke (5.0% vs 1.1%, $P = .06$) and major vascular complications (16.2% vs 1.1%, $P < .001$).[17]

On the other hand, the PARTNER A trial randomized high-risk patients deemed operable by the STS score to either transcatheter or surgical aortic valve replacement. The rate of death at 1 year from any cause was similar in both groups (24.2% vs 26.8%; $P = .44$), but again at the expense of higher rates of vascular complications (11.0% vs 3.2%, $P < .001$ at 30 days) and stroke (5.1% vs 2.4%; $P = .07$ at 1 year) in the transcatheter group. However, the surgical group had higher rates of major bleeding (19.5% vs 9.3%; $P < .001$) and new-onset atrial fibrillation (16.0% vs 8.6%, $P = .06$).[71]

Transcatheter aortic valve replacement has modernized the way we treat aortic stenosis and without a shred of doubt will become the standard of therapy for severe symptomatic aortic stenosis in patients who are not candidates for surgery. For the high-risk operable patient, the benefit of avoiding a sternotomy should be weighed against the higher risk of stroke and vascular complications with the transcatheter procedure. The availability of smaller delivery systems, better expertise, and better vascular access selection should decrease the rate of complications in the future.

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