Aortic valve stenosis: perioperative anaesthetic implications of surgical replacement and minimally invasive interventions

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Key points
Patients with aortic stenosis (AS) depend on preload, diastolic pressure, and systolic function, and are at risk of myocardial ischaemia.
Surgical aortic valve replacement remains the commonest intervention for symptomatic AS, but is associated with an unacceptable risk in some patients.
Minimally invasive transcather aortic valve intervention is an established alternative to surgery, particularly suitable for patients where surgical risk is prohibitive.
Echocardiography has a key role in the assessment of AS and the perioperative management of aortic valve interventions.
Transcather aortic valve intervention and surgical aortic valve replacement are associated with significant complications, for which the anaesthetist has a vital role in identifying and managing.

Aortic valve stenosis is the commonest indication for valve replacement in the western world with ~2% of the population aged more than 65 yr and 4% aged more than 85 having severe aortic stenosis (AS).

Pathophysiology and prognosis
AS is a progressive disease that may remain asymptomatic for decades with an associated low mortality. As severity progresses, there is increased left ventricular outflow obstruction and reduced left ventricular compliance leading to a reduction in myocardial function and reduced cardiac output. There is no definitive evidence that medical treatment can retard disease progression or impact on symptoms or survival. Severe but asymptomatic AS is associated with a risk of sudden death of <1%. Eventually, symptoms of angina, exertional syncope, or heart failure occur and the prognosis becomes poor with average survival being 2 yr, a 50% incidence of sudden death and a monthly mortality of ~2%. The pathophysiology of AS is shown in Figure 1.

Investigations for AS
Echocardiography
The key investigation in the diagnosis and assessment of AS is echocardiography. To assess the severity of AS, a comprehensive echocardiography examination should focus on the aortic valve, the consequences of AS, and the identification of incidental pathology. In particular, inspection of left ventricular dimensions and function, ascending aorta, mitral valve, left atrium, pulmonary artery pressure, and right ventricular function must be performed. Doppler examination of the aortic valve should include peak transvalvular flow velocity, mean pressure gradient, effective orifice area (EOA), and degree of any regurgitation (Figure 2). Left ventricular outflow tract (LVOT) obstruction should be excluded. Doppler studies can entrain errors, most frequently poor alignment. Gradient underestimation is minimized by using multiple views and the maximal and most clearly defined spectral velocity envelope. The dimensionless ratio of the LVOT to aortic valve velocity time interval can be useful and avoids errors related to LVOT diameter measurement, with a ratio of <0.25 consistent with severe AS (Figure 2). Echocardiographic evaluation shows that AS progresses with an average increase in jet velocity and peak valve gradient of 0.3 m s⁻¹ yr⁻¹ and 7–10 mm Hg yr⁻¹ respectively, and a decrease in valve area of 0.1 cm² yr⁻¹. Progression is more rapid with heavily calcified or bicuspid valves, coexisting ischaemic heart disease or renal failure and in patients more than 50 yr of age. The grading of AS is summarized in Table 1.

Other investigations for AS
Electrocardiography assesses left ventricular hypertrophy, ischaemia, sinus rhythm, and
conduction abnormalities, but is unreliable for confirming the diagnosis or severity of AS. The majority of patients will undergo coronary angiography to assess any co-existing coronary artery disease before valve intervention. Left heart catheter assessment of AS should be reserved for controversial or non-diagnostic echocardiographic findings. Magnetic resonance imaging or computed tomography should be performed when aortic root dilatation is detected on echocardiography to further assess the aortic root and ascending aorta.

**Low-grade AS**

The situation of low-flow, low-gradient AS should be suspected when the mean valve gradient is <30 mm Hg, but other echocardiographic indices suggest severe AS, particularly when the ejection fraction is <50%. Measured gradient depends on flow and valve area, and restricted valves need more force to open. Low-dose dobutamine may reveal an increase in the valve area of >0.2 cm² with minimal increase in gradient suggesting pseudosevere AS, or may reveal a fixed valve area but increased stroke volume and gradient, consistent with true severe AS. A failure to increase stroke volume by at least 20% indicates lack of contractile reserve and is consistent with significantly increased perioperative mortality although these patients may still benefit from intervention.23

**Risk assessment and decision making**

The three interventional options for severe symptomatic AS include surgical AVR, TAVI, or balloon valvuloplasty of the aortic valve (BAV). The decision to offer intervention depends on risk–benefit assessment. Surgical AVR remains the gold-standard intervention for severe AS. Despite a poor prognosis without intervention, at least one-third of patients with severe symptomatic AS are not offered surgical intervention because of high perioperative risk.23 4 Although the European System for Cardiac Operative Risk Evaluation (EuroSCORE) has been validated for predicting operative mortality for patients undergoing cardiac surgery, it is less reliable in predicting the outcomes in very high-risk or elderly patients. Cardiac risk score calculators also fail to account for local institutional outcomes and serious co-morbidities such as severe respiratory disease, frailty, or redo-sternotomy with patent grafts. The most important tool in patient risk assessment and decision-making remains overall clinical judgement. Patients with excessively high surgical risk should be referred to a multidisciplinary team (MDT) for comprehensive assessment and consideration of TAVI. A management strategy for patients with AS undergoing valve intervention or other cardiac surgery is summarized in Figure 3.23 3 Patients with severe AS have a clear indication for AVR if they have symptoms, a reduced ejection fraction, or are undergoing other cardiac surgery.

**General principles for aortic valve interventions**

**Preoperative visit**

The primary goal of anaesthesia preoperative evaluation is to quantify the patient’s perioperative risk, optimize co-existing morbidity such as congestive cardiac failure and pulmonary disease, and provide informed consent. Information on invasive monitoring,
Echocardiography, and postoperative care including ventilation in intensive care should be provided. Careful premedication to reduce anxiety-induced sympathetic response may be appropriate.

Monitoring, vascular access, and haemodynamic principles for AS

In addition to basic standard monitoring, an arterial line inserted before induction is recommended. The use of a large-bore peripheral cannula, central venous catheter, urometer, and temperature monitoring is routine. The use of a pulmonary artery catheter is less common, but depends on institutional preference, patient comorbidity, and assessment of left ventricular function. When general anaesthesia is used for aortic valve interventions, tracheal intubation is routine.

Haemodynamic goals for treating patients with AS include maintaining myocardial oxygen delivery via adequate systemic pressure and diastolic time, maintenance of contractility, and optimized preload for a non-compliant left ventricle aided by sinus rhythm with an ideal rate of 60–80 beats min⁻¹. When inducing and maintaining anaesthesia, many clinicians prefer an opioid-based technique to minimize vasodilatation and negative inotropy incurred with the inhalation agents and propofol. Haemodynamic support with alpha-agonists and fluids is ideal although a poorly functioning left ventricle may require inotropic support. Closed chest massage provides little gradient for blood flow across a stenotic aortic valve and defibrillation pads should be applied if TAVI, mini-sternotomy, or redo-sternotomy is being undertaken to ensure timely defibrillation if required.

Table 1 Grading of AS in adults. BSA, body surface area

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<th>Normal</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
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<tr>
<td>Aortic jet velocity (m s⁻¹)</td>
<td>&lt;2</td>
<td>&lt;3</td>
<td>3–4</td>
<td>&gt;4</td>
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<tr>
<td>Peak gradient (mm Hg)</td>
<td>&lt;10</td>
<td>&lt;40</td>
<td>40–65</td>
<td>&gt;65</td>
</tr>
<tr>
<td>Mean gradient (mm Hg)</td>
<td>&lt;5</td>
<td>&lt;25</td>
<td>25–40</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Valve area (cm²)</td>
<td>3–4</td>
<td>&gt;1.5</td>
<td>1.0–1.5</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Valve area indexed (cm² m⁻² BSA)</td>
<td>&gt;0.85</td>
<td>0.6–0.85</td>
<td>&lt;0.6</td>
<td>2.0</td>
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Based on 2008 Focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines."
Intraoperative echocardiography

For adults without contraindications, the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists practice guidelines suggest that TOE should be used in all open heart surgical procedures and used during TAVI if performed under general anaesthesia. Transthoracic echocardiography is routinely used for patients undergoing TAVI if performed without general anaesthesia. During the initial echocardiographic evaluation, diagnosis should be confirmed and previously unrecognized pathology excluded. During TAVI, echocardiography assists in confirming annulus diameter, wire guidance, device positioning, and may reduce contrast load. After prosthesis insertion, echocardiography aids de-airing after open surgery, quantifies valve function, identifies complications such as aortic regurgitation, LVOT obstruction, new myocardial ischaemia, and facilitates optimization of the haemodynamic status.

Surgical AVR

Indications for intervention

Surgical AVR is the gold-standard treatment for symptomatic severe AS, improving symptoms, quality of life, and prognosis. The weight of evidence is in favour of surgical AVR in the setting of moderate AS in patients undergoing coronary artery bypass graft surgery or surgery on the aorta or other heart valves. Although more contentious, surgical AVR should be considered in patients with asymptomatic severe AS with an abnormal exercise response (symptoms or hypotension) or a likelihood of rapid progression (as determined by age, valve calcification, and coronary heart disease), and in patients with mild AS undergoing coronary artery bypass graft surgery in whom there is evidence of rapid progression of disease such as moderate or severe valve calcification.

Surgery is most frequently undertaken with a full median sternotomy and requires cardiopulmonary bypass. The patient is positioned supine with arms wrapped by the sides. This provides good surgical access for other concurrent cardiac interventions particularly coronary artery grafting. Minimally invasive approaches to the chest for surgical AVR have been undertaken in an attempt to reduce postoperative pain, length of hospital stay and scarring, yet despite the obvious cosmetic advantage of a small skin incision, none of the reported techniques has proved superior to the standard complete median sternotomy in limiting postoperative complications and accelerating recovery. Stented bioprosthetic or mechanical valves are the most frequent prostheses used for AS surgery. Mechanical valves are more durable but require lifelong anticoagulation. Other valve options include stentless bioprostheses, aortic homografts, and the Ross procedure. Non-stented aortic valve options are technically more challenging, but avoid a reduction in EOAs caused by supporting stents.

Outcomes after surgical AVR

In-hospital and 30-day mortality is \( \sim 3.2\% \) for isolated AVR (with adverse event rates ranging from 1.5% for stroke to 10.9% for prolonged ventilations) and 5.6% when combined with coronary artery bypass grafting. Perioperative risk of AVR is influenced by left ventricular function, New York Heart Association functional class, and the volume of procedures performed at the hospital. The in-hospital outcome is also worse in patients with recent
myocardial infarction or renal failure, or those undergoing reoperation or emergency procedures.

Following AVR, life expectancy returns to near that of a control population. In patients more than 79 yr of age, although AVR is associated with an elevated 30-day mortality of 5.5%, survival at 1 and 5 yr is 87 and 65%, respectively. Age should therefore not be a contraindication to AVR. 

Intraoperative management

The intraoperative management of cardiac surgical patients and cardiopulmonary bypass is well covered in textbooks and will not be discussed in detail. Critical periods include induction of anaesthesia, sternal closure, aortic cannulation, and institution and withdrawal of cardiopulmonary bypass. Cardioplegia of a severely hypertrophied LV can be challenging particularly with aortic valve incompetence or coexisting coronary artery disease but can be aided by direct coronary ostial or retrograde coronary sinus plegia. In the majority of patients with adequate LV function and after correction of aortic valve incompetence, weaning from bypass is uneventful. When intraoperative complications occur, they frequently relate to poor ventricular function, air embolism, and bleeding. Ventricular epicardial pacing wires reduce the risks of immediate and delayed complete heart block.

Postoperative management and complications

Intensive care is routine for the postoperative care of patients undergoing surgical AVR for the timely detection and management of complications. Early postoperative complications include bleeding, tamponade, arrhythmias, and heart block. Systemic hypertension may stress suture lines or increase bleeding which may have a coagulopathic component after cardiopulmonary bypass. Air embolus after open-heart surgery can be delayed, occurring during patient transfer or in the intensive care and most frequently enters the right coronary artery leading to acute right ventricular failure or arrhythmia. After aortic valve intervention, patients with a well-functioning small hypertrophied left ventricle are particularly at risk of LVOT obstruction including systolic anterior motion of the anterior mitral valve leaflet. Tamponade should be suspected in the setting of a low arterial pressure and high filling pressures, or in any low output state. Given the possible differentials (including LVOT obstruction, ischaemia, valve dysfunction, and bleeding), echocardiography is valuable but cannot reliably exclude tamponade. Resuscitation after sternotomy should follow cardiac intensive care guidelines and, in addition to excluding airway and breathing problems, should focus on early defibrillation or pacing and early reopening, in preference to chest compressions and bolus adrenalin.

Transcatheter aortic valve implantation

TAVI is a less-invasive therapeutic alternative when surgical AVR is contraindicated because of technical limitations or when comorbid states amount to prohibitive surgical risk. The current technique of TAVI is now well established using two devices, the balloon-expanded Edwards SAPIEN valve stent (Edwards Life Sciences, Irvine, CA, USA), and the self-expanding Medtronic CoreValve ReValving system (Medtronic Inc., Minneapolis, MN, USA). It is commonly undertaken using a retrograde approach via the femoral or other major artery, or by an antegrade transapical approach through the apex of the left ventricle via an anterolateral thoracotomy. Implantation involves crossing the stenosed native aortic valve with a wire followed by balloon valvuloplasty and then deployment of the bioprosthesis within the annulus.

Current issues when considering TAVI

TAVI continues to develop rapidly with improving technology and increasing clinical experience expanding the population eligible for this procedure. Factors that require particular thought when considering TAVI include unknown long-term durability of the prosthesis and a high incidence of both para-valvular leak and pacemaker requirement. Neurological and vascular complications are expected to reduce with technical advancements. Finally, TAVI outcomes from published trials and specialist centres are often better than registry results, reinforcing the concept that TAVI should be undertaken in high-volume specialized centres utilizing the expertise of an MDT, including cardia anaesthetists.

Indications for intervention

Current indications for TAVI include severe symptomatic AS in conjunction with a high perioperative surgical risk for AVR (logistic EuroSCORE ≥20 or Society of Thoracic Surgeons Predicted Risk of Mortality Score—STS-PROM ≥10), or a contraindication to surgery such as porcelain aorta, severe kyphoscoliosis, significant cirrhosis, or extensive mediastinal radiotherapy. Contraindications include life expectancy <12 months, existing mechanical aortic valve or endocarditis, severe organic mitral regurgitation, coronary artery disease requiring surgical intervention, and no suitable access route.

Outcome after TAVI

Procedural success for TAVI is reported at 98% with 30-day mortality <5%. In this high-risk patient group, significant symptom improvement and a reduction in hospitalization occurs but perioperative morbidity includes a stroke rate of up to 5% and major vascular complications of 10–15%. Outcomes after transapical procedures may be inferior to transfemoral TAVI, but the former involves a mini-thoracotomy undertaken in patients often suffering from significant peripheral vascular disease. Late mortality relates primarily to comorbidities including stroke and congestive heart failure.
Environment

TAVI is ideally undertaken in a hybrid operating-angiography suite with the patient in a supine position with arms wrapped by the sides, and the left chest slightly elevated if a transapical TAVI approach is used. Theatre personnel usually include a cardiac anaesthetic team, interventional cardiology team, surgical team, perfusionist, and echocardiographer. Equipment will include a cardiac angiography table with mobile gantry, anaesthetic machine and equipment, surgical trolleys, cardiopulmonary bypass machine and cell saver, multiple imaging screens, and echocardiography equipment. Frequently in a location remote from main theatres, this room can become crowded and noisy.

Anaesthetic for TAVI

General haemodynamic principles for managing patients with AS undergoing TAVI are outlined in the previous section. For transvascular TAVI, some centres preferentially undertake trans-femoral or subclavian TAVI under local anaesthesia with sedation to minimize haemodynamic instability and short total procedure and recovery times. However, patient immobility during valvuloplasty and valve deployment is less reliable, managing major complications is more challenging, and the use of echocardiography during the procedure is more limited. Emergent conversion to general anaesthesia must be planned for. For transapical TAVI, patients frequently receive perioperative anticoagulation with aspirin, clopidogrel, and heparin, and the procedure is performed under general anaesthesia with a single lumen tracheal tube. Echocardiography is used to identify the left ventricular apex, a small incision made and the left ventricular cavity accessed with a Seldinger technique. Propofol and remifentanil, often with low-dose vasopressor or inotrope, is one technique that facilitates this while providing haemodynamic stability during a minimally stimulating procedure. Patient-controlled analgesia, intercostal blocks, and paracetamol provides satisfactory analgesia. The majority of patients undergoing TAVI will be extubated at the end of the procedure and may be able to return to a cardiac ward or a high dependency unit. However, postoperative care must include identification and management of arrhythmias and pacing, chest drains, surgical incisions, and large vascular access devices.

Haemodynamic manipulation

During TAVI, temporarily minimizing cardiac motion and reducing left ventricular output with rapid ventricular transvenous pacing (and ideally apnoea) aids ideal device positioning and minimizes displacement during balloon valvuloplasty and prosthesis deployment. Effectiveness is confirmed using echocardiography and the arterial line trace. Haemodynamic complications of rapid ventricular pacing are minimized by ensuring adequate pre-pacing arterial pressure and even pre-emptive vasopressor in particularly fragile patients. The transvenous pacing wire can be used in the case of complete heart block, and this (or epicardial wires after transapical approach) is left in situ immediately after operation in case of delayed heart block.

In emergency cases or in patients with an ejection fraction <20%, consideration of initiating elective femoral–femoral bypass should be discussed because significant haemodynamic instability should be expected. A plan for initiation of rescue cardiopulmonary bypass or open surgery should be rehearsed by the perioperative team.

Periprocedural complications during TAVI

Hypovolaemia, hypotension, ischaemia, and arrhythmia are all poorly tolerated and must be vigilantly looked for. Resuscitation after TAVI is less well described but should consist of early identification of the cause and consideration of emergency cardiopulmonary bypass. The anaesthetist, frequently aided by echocardiography, is intimately involved in the recognition and management of complications, some of which are discussed below.

Vascular and neurological complications

Arterial injury can include tearing or avulsion near the access point, aortic dissection, or annulus rupture. Device embolization is usually well tolerated if the valve remains axially aligned with flow and does not occlude major aortic branches, and a second device can be deployed in the correct position. Neurological events including delirium, seizure and stroke, caused by atheroma, calcific or air embolization, dissection, or hypotension are more easily assessed with awake patients, although they can require general anaesthesia for ongoing management.

Cardiac complications

Manipulation of wires can interfere with the mitral valve apparatus or cause poorly tolerated arrhythmias or tamponade. Apical access, while reducing vascular complications, increases risks of respiratory complications and right ventricular injury. When it occurs, coronary artery obstruction is often because of displaced calcified leaflets that are particularly bulky, or when a short annulus-ostial distance has been unrecognized before operation, but can also be because of device malposition.

Prosthetic valve regurgitation

Following TAVI, minor paravalvular regurgitation occurs in more than 50% of patients but about 15% of patients have at least moderate regurgitation, probably as a result of calcification preventing complete occlusion of the paravalvular space. This may be improved by further balloon re-expansion. Previously, often accepted and felt to be transient, recent evidence shows an association with increased in-hospital death, less symptom improvement, and higher longer term mortality.

Anaesthetic management of complications

Any persisting haemodynamic instability in this patient group will require urgent assessment and simultaneous intervention.
Myocardial ischaemia is common and initial treatment should be aimed at restoring myocardial perfusion pressure with vasopressors and completion of device deployment to treat aortic regurgitation resulting from valvuloplasty. Depending on the situation, other intervention may include emergent intra-aortic balloon pump, emergent (peripheral) cardiopulmonary bypass, percutaneous coronary intervention, vascular control, and volume resuscitation or emergent sternotomy. In the case of vascular injury, temporary balloon occlusion, endovascular stenting, or open surgery may be required. During device deployment, early cardioversion or chest compressions should be delayed until deployment is complete, and the prosthesis checked afterwards.13

Balloon valvuloplasty of the aortic valve
Indications for intervention

Although the evidence is contentious, specific clinical scenarios where BAV can be considered include as a bridge to surgery for haemodynamically unstable patients at high risk for surgical AVR or TAVI, to facilitate urgent major non-cardiac surgery, or for palliation in patients with serious comorbid conditions that preclude TAVI or AVR.2,3

Percutaneous balloon aortic valvuloplasty (BAV) is a procedure in which a balloon is positioned across the stenotic aortic valve and inflated to relieve the stenosis by fracturing calcific deposits, annular stretch, and commissure separation. Despite a reduction in transvalvular pressure gradient accompanied by an improvement in symptoms, the mean post-procedure valve area is ≏ 1.0 cm².2,4 Serious complications including stroke, aortic regurgitation, myocardial infarction, and death occur in ~15% of patients, re-stenosis is frequent at 6 months,3,14 and longer term outcome is unchanged. Balloon valvuloplasty can be undertaken using local anaesthesia, although some of these patients will be critically unwell with cardiogenic shock, pulmonary oedema, or multiorgan failure, requiring anaesthetic and intensive care involvement.

Conclusions

Aortic valve intervention improves survival and reduces symptoms in patients with severe AS. History and echocardiography define when intervention is required. Surgical valve replacement can be undertaken with very low morbidity and mortality in the majority of patients. For high-risk patients, decision-making should involve a MDT, including anaesthetists and encompass consideration of TAVI. The continued development of TAVI and further experience will reveal the full potential of this new technology. There remains a limited role for BAV.

The key to providing safe effective anaesthesia for these procedures is understanding the pathophysiology of AS, knowledge of echocardiography and of the processes and potential complications of the complex procedures now being undertaken. Anaesthetists have a vital role in the perioperative MDT management of these potentially complicated patients.

Declaration of interest

None declared.

References


Please see multiple choice questions 13–16.