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REVIEW ARTICLE

Anesthetic and Perioperative Considerations for Transapical Transcatheter Aortic Valve Replacement

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AORTIC VALVE REPLACEMENT (AVR) continues to be the standard for treatment of aortic stenosis. The overall operative mortality for patients undergoing a surgical AVR (SAVR) ranges from 2.5%-4%.1–4 With increasing age, the risk for octogenarians and nonagenarians ranges between (4.9% and 9.6%), and this can be as high as 25% in patients with significant co-morbidities.1,5–7 As such, up to 30% of these patients are not considered candidates for traditional open surgical intervention.8,9 Balloon aortic valvuloplasty results in only temporary relief of symptoms by a small increase in valve area.10–12 In 2002, Cribier performed the first catheter-based aortic valve replacement in a human, and in 2007, transcatheter aortic valve replacement (TAVR) was introduced into commercial use.13,14 According to the Placement of Aortic Transcatheter Valve (PARTNER) trial, TAVR reduces mortality in high-risk patients who are not candidates for surgical intervention.15 The technology has evolved rapidly and TAVR is now used routinely. In Europe, 23% of tissue valves in elderly patients are TAVR.16 Experience with this technology also is growing in North and South America, the Middle East, and Asia.17 The two commonly used approaches to TAVR are transfemoral (TF) and transapical (TA).15,18 Other access options include axillary/subclavian artery and the direct aortic approach.19–21 In Europe, TA-TAVRs comprise about 16% of TAVR cases.22 Each approach presents a unique challenge to the anesthesiologist. The present study is a review of (1) the specific characteristics of the TA-TAVR population that make them distinct from those patients undergoing TF-TAVR, (2) the different approaches to providing anesthesia for these patients as reported in the literature, and (3) the procedural steps particular to these cases so that anesthesiologists are able to anticipate intraoperative events and issues in a proactive fashion.

PATIENT SELECTION AND PREOPERATIVE RISK ASSESSMENT FOR TA-TAVRS

The transapical approach has evolved over the past 5 years as an alternative for patients under consideration for TAVR with unfavorable iliofemoral artery anatomy (Fig 1). Many centers use a “transfemoral first” or “groin first” approach, as recently reported in the US PARTNER trial.15,23 This strategy selects for a cohort of high-risk patients as candidates for the TA-TAVR procedures24 (Table 1). Patients chosen for TA-TAVR have higher rates of diabetes and dyslipidemia with concomitant increased rates of peripheral vascular disease, porcelain aortas, and history of previous myocardial infarction compared with patients chosen for TF-TAVRs.9 When authors have specifically studied pre-procedure risk scores, mean STS scores (Society of Thoracic Surgeons scores) and logistic EuroSCOREs (European System for Cardiac Operative Risk Evaluation scores) are higher for patients undergoing transapical procedures.24 Indeed, there is one review of TA-TAVR with a mean logistic EuroSCORE of 48.24 It should be noted that both the STS score and the EuroSCORE were designed to predict mortality for cardiac surgery patients. While the EuroSCORE was designed for all cardiac surgery patients, the bulk of the model is based on coronary artery bypass graft patients.25

The STS score is more accurate for evaluating the risk of patients undergoing aortic valve replacement alone,3,25,26 The applicability of these scores to TAVR patients has been reviewed.27 The logistic EuroSCORE tends to overestimate the risk in TAVR patients.28 This also appears to be the case for the new EuroSCORE II.29 Therefore, the STS risk model may be a better predictor of outcome in these patients.25 Of note, other factors such as frailty of the patients also should be considered.23,30,31 A risk factor analysis for patients undergoing TA-TAVR and not using the groin-first approach found that reduced pulmonary function as measured by vital capacity and mitral regurgitation were risk factors for 30-day mortality, in contrast to the STS score and EuroSCORE, which were not predictive.32 Severity of tricuspid regurgitation also has been identified as a risk factor for death.33 A new method to risk stratify these patients is needed.
Surgical Procedure

A detailed description of the technical considerations of the TA-TAVR procedure has been described previously\(^\text{33}\) (Fig 2, Video clip 1). There are particular aspects important to anesthesiologists that deserve attention. At most institutions, TA-TAVRs and TF-TAVRs are done in either a cardiac catheterization laboratory or in a hybrid surgical suite. The TAVR team is multidisciplinary and includes cardiac surgery, anesthesia, perfusion, and cardiology. The TA-TAVR approach requires a left anterior lateral minithoracotomy and a transapical puncture of a beating heart and, hence, is more invasive than TAVR done with transfemoral access. The patient is positioned with the left chest elevated to facilitate exposure of the minithoracotomy. This is done through the fifth or sixth intercostal space to expose the apex of the ventricle. After suturing epicardial pacing wires and pericardial stay sutures, apical purse-string sutures with pledgets are placed to create an internal diameter of 1 to 2 cm.\(^\text{23,24}\) Typically, the introducer that the surgeon places through the apex of the heart ranges between 18F and 22F (Fig 3). Anticoagulation is achieved with heparin administration, before placing the larger sheath, and is maintained at an activated clotting time (ACT) of approximately 250 to 300 seconds. Toward the end of the procedure, this is reversed with protamine sulfate. Identification of the true apex is preferable to the left ventricular free wall, because there is lower tension due to the greater convexity (Laplace’s law) and it avoids the distal left anterior descending artery. This has obvious implications for suture retention and postoperative bleeding.\(^\text{33}\) Rapid ventricular pacing is required during balloon valvuloplasty and during deployment of the Edwards SAPIEN prosthetic valve. The purpose of rapid pacing is to momentarily decrease ventricular outflow to minimize the risk of valve migration. This is accomplished during inflation, at a rate of 160 to 220 beats/min, either by transvenous pacing wires or epicardial electrodes. The goal is to achieve systolic blood pressure < 70 mmHg with a pulse pressure < 20 mmHg.\(^\text{35,36}\) Medtronic (Minneapolis, MN), which does produce valves for TF-TAVRs, currently does not have a valve approved for TA-TAVRs. Edwards SAPIEN (Edwards Lifesciences, Irvine, CA) currently has only three valve sizes available in the United States (23 mm, 26 mm, and 29 mm). After valve deployment, the function of the valve must be assessed with attention given to the presence of and severity of aortic regurgitation. Incidence of any paravalvular regurgitation is approximately 85% and is frequently minor.\(^\text{35}\) If significant or greater than mild regurgitation is diagnosed, reinflation of the balloon can be helpful in cases of incomplete prosthesis expansion and poor coaptation with the wall; however, a secondary device or valve within a valve or even an AMPLATZER™ Septal Occluder device may be considered.\(^\text{37}\) After valve deployment and subsequent removal of the delivery sheath, the apical purse-string sutures are secured and the thoracotomy is closed.

Procedural Complications

While the precise rate of complications is difficult to evaluate given the differences in definitions and reporting between authors, trends can still be observed.\(^\text{38}\) Apical bleeding has been described as an “Achilles heel” of the TA-TAVR procedure, occurring in 2% to 5% of TA-TAVR cases\(^\text{1,22,33,39}\) (Table 2). The introduction of apical closure devices may help mitigate some of this risk.\(^\text{23,40}\) Complications regarding suture dehiscence can present as an acute catastrophic hemorrhage.\(^\text{41}\) Subacute and chronic presentations of apical pseudoaneurysms are also well documented.\(^\text{33,42–45}\) Bleeding from the intercostal arteries also may be clinically relevant.\(^\text{46}\) Unique to TA-TAVR cases, fatalities resulting from intramyocardial hemorrhage/dissection may occur. Such instances occur from trauma to the septum while advancing the device and from the apical puncture.\(^\text{33}\) Transapical access, low weight, and underlying coronary artery disease were risk factors for bleeding in TAVR cases.\(^\text{47}\) In a review of 4,571 cases, there was a significantly higher rate of transfusion requirement in TA-TAVR versus TF-TAVR patients (20.8% v 15%, p < 0.01).\(^\text{25}\) Although often showing trends in greater bleeding with TA-TAVR compared with TF-TAVR cases, other smaller reviews are less consistent.\(^\text{1,9,47,48}\) Periprocedural hypertension raising ventricular wall tension increases the risk of bleeding, left apical access.
tear, myocardial dissection, and pseudoaneurysm formation. Injury to the distal left anterior descending artery causing apical ischemia may predispose to suture dehiscence.49

Predictably, bleeding events negatively impact survival after TAVR.31 Importantly, the clinical implication of a major vascular event is not the same for the two procedures. According to the SOURCE registry, there was no statistically significant difference in 30-day survival between TF-TAVR and TA-TAVR patients from a single institution, the need for reintubation was 11.3%.51 Similarly, in a slightly larger multicenter trial of 150 TA-TAVR patients, 8.7% of patients were considered to have respiratory failure.52 Postprocedure pleural effusions have been reported to occur in 18% to 26% of patients.9,52 Poor respiratory function defined as a vital capacity less than 70% has been observed to be an independent risk factor for perioperative mortality in a review of 299 TA-TAVR patients, of less that 70% has been observed to be an independent risk factor for perioperative mortality in a review of 299 TA-TAVR patients, of which 11.3% died in the hospital, 7 patients (44%) died within the first 24 hours postprocedure.56

The Valve Academic Research Consortium, which standardized endpoints for TAVRs to be used in large outcome studies, and recently revised their endpoints to be more clinically relevant given the need for intubation and the presence of a thoracotomy incision. In one small review of 53 TA-TAVR patients and is a significant problem that the perioperative providers must address. The prevalence of chronic obstructive pulmonary disease among patients presenting for TA-TAVR appears similar to patients having TF-TAVRs and ranges between 20% to 40%.1,22,23 However, the consequences of preexisting pulmonary disease in TA-TAVR patients may be more clinically relevant given the need for intubation and the presence of a thoracotomy incision. In one small review of 53 TA-TAVR patients from a single institution, the need for reintubation was 11.3%.31 Similarly, in a slightly larger multicenter trial of 150 TA-TAVR patients, 8.7% of patients were considered to have respiratory failure.52 Poor respiratory function defined as a vital capacity less that 70% has been observed to be an independent risk factor for perioperative mortality in a review of 299 TA-TAVR patients.53 In a review from Canada of 135 TA-TAVRs, of the 16 patients who died in the hospital, 7 patients (44%) died within the first 24 hours postprocedure.56

Table 1. Demographic characteristics

<table>
<thead>
<tr>
<th>Demographic Characteristics</th>
<th>Di Mario50</th>
<th>Thomas1</th>
<th>Gilard46</th>
<th>Rodes-Cabau66</th>
<th>Gurvitch45</th>
<th>Guinot9</th>
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<tr>
<td>EF &lt;50%</td>
<td>36.2</td>
<td>37</td>
<td>59.4</td>
<td>47.9</td>
<td>67.9</td>
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<td>Coronary Artery Disease (any)</td>
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<td>25</td>
<td>50.3</td>
<td>30.2</td>
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<td>Previous MI</td>
<td>2.9</td>
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<td>15.1</td>
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<tr>
<td>COPD (any)</td>
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<td>59.1</td>
<td>30.2</td>
<td>15.1</td>
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<td>3.1</td>
<td>17.3</td>
<td>28</td>
<td>25</td>
<td>11.7</td>
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<tr>
<td>Peripheral Vascular Disease</td>
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<td>3.1</td>
<td>20.6</td>
<td>27.7</td>
<td>25</td>
<td>11.7</td>
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<td>Porcelain Aorta/Severe Aortic Calcification</td>
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<td>3.1</td>
<td>17.3</td>
<td>28</td>
<td>25</td>
<td>11.7</td>
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<tr>
<td>Previous Stroke</td>
<td>12.9</td>
<td>3.1</td>
<td>20.6</td>
<td>27.7</td>
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<td>11.7</td>
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<tr>
<td>Dialysis</td>
<td>16.3</td>
<td>3.1</td>
<td>20.6</td>
<td>27.7</td>
<td>25</td>
<td>11.7</td>
</tr>
<tr>
<td>Mean Logistic EuroSCORE</td>
<td>22.2 (±14.2)</td>
<td>29.1 (±16.3)</td>
<td>24.8 (±14.7)</td>
<td>25 (17-34)</td>
<td>25 (17-34)</td>
<td>11.2 (11-24)</td>
</tr>
<tr>
<td>Mean STS-PROM</td>
<td>15.1 (±13.8)</td>
<td>13.8 (±13.8)</td>
<td>15.5 (±6.9)</td>
<td>12.2 (16-24)</td>
<td>15 (15-20)</td>
<td>15 (15-20)</td>
</tr>
</tbody>
</table>

Values are expressed as means or percentages. EuroSCORE and STS-PROM are expressed as mean values ± standard deviation. Standard deviation was not available for Gurvitch et al. Interquartile range (25th to 75th percentile) rather than standard deviation was used by Guinot et al.

Abbreviations: CABG, coronary artery bypass graft; COPD, chronic obstructive pulmonary disease; EF, ejection fraction; EuroSCORE, European System for Cardiac Operative Risk Evaluation; MI, myocardial infarction; STS-PROM, Society of Thoracic Surgeons Predicted Risk of Mortality; TA-TAVR, transapical transcatheter aortic valve replacement; TF-TAVR, transfemoral transcatheter aortic valve replacement.
patients. Most of these are clinically silent. In the PARTNER trial, the risk of neurologic events (strokes and transient ischemic events) at 30 days was 5.5% and at 1 year was 8.3%. Relevant to the perioperative physician, the risk of stroke is highest within the first week after TAVR. In general, predictors of clinically detectable stroke after TAVR include a history of a prior stroke, severe atheroma, and smaller aortic valve area. During TA-TAVR procedures, air entrained from the apical access site often can be visualized on TEE. Calculated debris from the aortic valve and aortic atheroma also can embolize. It has been hypothesized that the TA-TAVR approach, which largely avoids manipulation of large 22F and 24F catheters in the aortic arch, might have a lower rate of embolic complications. However, available data do not support this. When patients were evaluated separately with transcranial Doppler and magnetic resonance imaging, no significant differences were observed between the 2 procedures. The accumulation of silent strokes over time may contribute to cognitive impairment. Cognitive function assessed with neuropsychological testing after TA-TAVRs is mild and thus far does not seem to correlate with cerebral embolic burden. Data from the SOURCE registry suggest that despite the higher rate of carotid disease in the TA-TAVR group, the clinical stroke rates at 30 days are similar. Similar lack of statistical difference was seen in the larger Transcatheter Valve Treatment Sentinel Pilot Registry.

Although preexisting conduction abnormalities are similar in SAVR and TAVR patients, ranging between 40% to 50%, the need for permanent pacemaker post-TAVR is higher, and rates as high as 15.5% have been reported. In TA-TAVR patients, who currently only receive an Edwards SAPIEN valve, the rates of heart block range from 7% to 13.6%. Importantly, the Medtronic CoreValve, which is currently used only in TF-TAVRs, is associated with a significantly higher rate of postprocedure pacemaker dependence than in patients receiving the Edwards SAPIEN valve. Differences in valves rather than aspects of the procedure likely account for occasional differences in the need for a pacemaker postprocedure between TA and TF patients. In TA-TAVRs, the presence of epicardial pacing leads decreases the immediate significance of conduction disturbances during the procedure, but clearly such complications add to the complexity of the perioperative care. Most conduction abnormalities occur during or immediately after the procedure. New-onset atrial fibrillation is more likely in patients undergoing TA-TAVR than in patients having TF-TAVR. The use of epidurals may decrease the rate of postprocedure atrial fibrillation. Myocardial infarctions appear uncommon in both TA-TAVRs and TF-TAVRs.
Development of renal failure requiring dialysis also appears to be less than 1% in both TA and TF-TAVR. The need to convert to an open sternotomy also does not appear to be statistically different between both approaches and, in the larger reviews, is generally less than 5%. Residual aortic regurgitation in TAVRs is associated with higher in-hospital and long-term mortality. For correct functioning of a TAVR valve, it is important that the prosthesis reaches its final ex vivo shape after implantation. The calcification of the native aortic valve and annulus may lead to stent deformation and a noncircular stent shape with resulting leaflet distortions. There may be subtle differences between TA-TAVRs’ and TF-TAVRs’ valve deployment, resulting in a greater degree of leaflet asymmetry in TA-TAVR cases. The clinical implications of this subtle finding are unclear. Most residual aortic regurgitation in TAVRs is paravalvular rather than central. In a review of more than 1,000 patients, postprocedure moderate-to-severe aortic regurgitation was observed in 1.5% of TF patients and 2.3% of TA patients. Two of the procedural complications are listed in Table 2.

Table 2. Procedural Complications

<table>
<thead>
<tr>
<th>Complications</th>
<th>Di Mario22</th>
<th>Thomas1</th>
<th>Gilard46</th>
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<td>TA-TAVR</td>
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<tr>
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<tr>
<td>Transfusion</td>
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<table>
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<td>Vascular (major)</td>
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<td>Bleeding (major)</td>
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<td>30 All-Cause Mortality</td>
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<td>6.3</td>
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NOTE. Values are expressed as percentages. Definitions are based on the Valve Academic Research Consortium criteria. Abbreviations: TA-TAVR, transapical transcatheter aortic valve replacement; TF-TAVR, transfemoral transcatheter aortic valve replacement.
strongest predictors of regurgitation appear to be valve sizing and the extent and asymmetric distribution of calcium. Access route is not discussed in the literature as a predictor of residual regurgitation. Patient prosthetic mismatch occurs in 7.6% of TA-TAVRs and appears to be associated with a considerably increased risk of early mortality. However, again the rates of mismatch in TA-TAVRs appear similar to TF-TAVRs.

The long-term outcomes in TA and TF-TAVR cohorts in the PARTNERS trial are not significantly different. This is mirrored in a multicenter Canadian study. However, an anesthesiologist focused on a patient’s perioperative care may be more concerned with immediate short-term outcomes. The 30-day experience reported by the same Canadian study found a trend toward a slightly higher mortality for the TA-TAVR (n = 177) 11.3% than TF-TAVR (n = 168) patients 9.5%. This difference also was seen in other larger studies. According to a study of 1,038 patients using the Edwards-SAPIEN Aortic Bioprosthesis European Outcome (SOURCE) Registry of TAVR cases from Jan 2007 to Jan 2009, there was higher 30-day mortality for patients undergoing transapical valve placement (6.3% v 10.3%). The Transcatheter Valve Treatment Sentinel Pilot Registry, in which a total of 4,571 patients underwent TAVR between January 2011 and May 2012 in 137 European centers across 10 countries, was reviewed. The mortality rate again was lower in transfemoral (5.9%) than in transapical (12.8%) patients. In 40 “extreme risk” patients with EuroSCORES > 35% having TA-TAVRs, there was a 5% on-table death rate and 20% in-hospital mortality. The high-risk nature of the procedure itself also may contribute to these trends. In the French Aortic National CoreValve and Edwards (FRANCE 2) Registry of over 3,000 TAVR patients, TA-TAVR was an independent predictor of decreased survival. The Transcatheter Aortic-Valve Replacement versus Surgical Aortic-Valve Replacement in Low-Surgical Risk Elderly Patients with Aortic Stenosis (STACCATO) trial was discontinued early because of increased 30-day adverse events rate (mortality, stroke, and renal failure) in the TA-TAVR versus SVGAR arm (14.7% v 2.8%). The mean STS score in this prospective study was only 3.1 in the TA-TAVR group.

It is important to consider the presence of a learning curve when interpreting TAVR outcome data. Multiple institutions have reported that outcomes improve as TAVR teams gain experience. However, the impact of the learning curve on 30-day survival outcomes is unclear. In one review of 101 TA-TAVRs in a single institution, there was a strong trend toward improvement in hospital mortality from 17.6% in the first half to 7.8% in the second half. The same trend was evident in a slightly larger institutional review of 299 patients, in which the 30-day mortality fell from 11.3% in the first half to 6.0% in the second. However, neither of these studies was statistically significant. A multi-institutional review of 2,339 patients from the SOURCE registry reported that while the frequency of procedural complications trended down over a two-year period, reflecting a learning curve, the 30-day mortality remained unchanged. Other clinicians have advocated that the use of a structured training may favorably benefit TA-TAVR outcomes. The institution reviewing their experience of 500 TA-TAVR cases using a system of external and internal proctoring to new members of the team had a much lower than expected 30-day mortality rate of only 4.6%.

ANESTHETIC CONSIDERATIONS FOR TA-TAVR

The Heart Team in TAVRs

Although a team approach to the care of patients has been a longstanding and integral part of clinical practice in other medical fields, such as oncology and organ transplant programs, only more recently has it been emphasized in the care of cardiovascular patients. The importance of a multidisciplinary approach to patient care is particularly relevant in TAVR patients given the complexity of these procedures. The heart team approach is in fact mandated by the Food and Drug Administration and The Centers for Medicare and Medicaid Services. The composition of the team can vary by institution and adjusted to fit the specific needs of a given clinical scenario. In general, the team will involve not only cardiologists and surgeons, but also cardiac anesthesiologists who are vital not only to the technical success of the procedure, but also have a role in patient selection and the access route chosen. The implementation of a heart team strategy clearly carries with it the usual logistical hurdle of bringing a multidisciplinary team together. As precise choreography of TAVR is absolutely mandatory for its success, this initial investment in gathering and involving all the members of the heart team in planning the procedure is crucial.

Induction and Maintenance

Principal goals for the anesthesiologist in TA-TAVR cases include maintaining hemodynamic stability, avoiding on-table patient movement, and achieving early extubation. Given the invasive nature of the procedure and the need for transesophageal echocardiography (TEE), most institutions use general anesthesia. Double-lumen endotracheal intubation, although historically used in earlier TA-TAVRs, generally is unnecessary. Moreover, single-lung ventilation could have unfavorable cardiopulmonary implications in these cases. Two institutions have reported performing TA-TAVRs with patients awake relying on epidurals for pain control. In one of these reports, 2 of 7 patients were converted to general anesthesia. One patient had a panic attack and another required sternotomy. Although sedation for these cases may be feasible, the authors of this paper would advise caution with such an approach, given the potential procedural complications described. This is in contrast to TF-TAVRs, in which the role of local anesthesia with sedation largely has been established, is practiced routinely on the European continent, and is being used in a small but growing number of centers in the United States. Neurmuscular blockade is advised to prevent catastrophic patient movements during valve deployment. Implications of such movements or coughing include poor placement of the valve, paravalvular leak, valve embolization, and aortic dissection. As in any case, the choice of medications to achieve and maintain general anesthesia is less important than how they are used. Short-acting intravenous medications should be considered to facilitate rapid extubation. The adoption of a “fast-track” protocol for this group of patients should be considered.
Access and Monitoring

The anesthesiologist’s plan for intravenous access and monitoring in a TA-TAVR should be similar to that for a surgical AVR. Central venous access is required for the administration of inotropic medications and fluids to facilitate rapid resuscitation in emergencies. Strong consideration needs to be given to arterial and venous groin access for the possibility of emergent cardiopulmonary bypass. An arterial line is mandatory. The use of a pulmonary artery catheter can be helpful with the management of hemodynamic instability, especially after rapid pacing and valve deployment. Hemodynamic management of patients with poor ventricular function can be particularly challenging during this period and makes the presence of a pulmonary artery catheter quite valuable. Cerebral oximetry and noninvasive cardiac output monitoring devices have been used and can provide additional helpful data. Transesophageal echocardiography in TA-TAVR patients has a uniquely important role and will be discussed below. Given the small size of the thoracotomy and difficulty using internal paddles, external pads placement in advance is required.

Echocardiographic Evaluation

Echocardiography in TAVRs has been reviewed in depth elsewhere. The use of perioperative TEE in TAVRs is variable, because it commonly requires the use of general anesthesia. Although there are centers that perform TEE on sedated patients during TF-TAVRs, this practice is uncommon. Alternatives to TEE for TF-TAVRs done under sedation include transthoracic echocardiography, nasal TEE, and intracardiac echocardiography. In contrast, most centers that perform TA-TAVRs use general anesthesia, facilitating the use of a TEE probe. Use of TEE in TF-TAVRs and in TA-TAVRs can be helpful, because there are many similar steps involved in these procedures, such as determination of the annular size and measuring the distance between the coronary ostia and the aortic annulus. Real-time 3D-TEE may improve the accuracy of these measurements in both TA-TAVR and TF-TAVR cases. Intraoperative TEE during TA-TAVRs has two additional roles that are not seen in TF-TAVR. Echocardiographic imaging aids the surgeon in the identification of the true left ventricular apex, for which a three-dimensional x-plane can be helpful. Trans-thoracic and apical epicardial echocardiography also have been used for this purpose. As previously discussed, accessing the true apex may have implications for postoperative bleeding, given the decreased wall stress at this point. Additionally, accessing the free wall of the ventricle can result in the axis of the needle and guidewire oriented toward the mitral valve rather than the aortic valve. Accurate ultrasound imaging also is needed to ensure that the guidewire and device are not entangled in the mitral valve apparatus, because this can cause severe mitral regurgitation. Occasionally, structural damage such as severed chordae may result from the guidewire acting in a “cheese-cutter” fashion. After valve

![Fig 4. Identification of left ventricular apex with three-dimensional echocardiography and x-plane imaging. Various modes of echocardiography have been found to be helpful in the identification of the true left ventricular apex, including three-dimensional x-plane imaging. In this image, x-plane imaging is used in real time as the surgeon palpates the apex of the heart. The decreased wall stress at the apex (Laplace’s law) may have implications for postoperative bleeding. Additionally, accessing the free wall rather than the apex of the ventricle can result in the guidewire being directed toward the mitral rather than the aortic valve. (Color version of figure is available online.)](image-url)
deployment, the valve must be assessed for regurgitation. Small paravalvular leaks that do not occupy a significant portion of the ventricular outflow tract, do not exhibit any proximal convergence zones above the deployed valve and do not show any flow reversal in the aorta can be left alone. Other approaches that can be considered in evaluating the severity of regurgitation include comparing the Doppler-derived stroke volumes in the right and left ventricular outflow tracts; the proportion that the prosthetic circumference the jet, or sum of the jets, occupies also can be used. Punctuate leaks are caused by inadequate inflation of the device or calcifications in the native valve that leaves a gap between the annulus and the prosthesis preventing a good seal. The guidewire itself can interfere with cusp coaptation leading to central regurgitation, but removing the wire can resolve the problem. Moderate-to-severe paravalvular leak has been estimated to occur in 11.7% of cases and should be addressed given the negative impact on survival (Fig 6). Given the complexity of TAVR cases and the presence of what has been described as the “golden hour” of a TAVR procedure, the echocardiographer must be focused wholly on the echocardiographic examination to provide reliable data for rapid clinical decisions. It is very helpful to have a dedicated physician who is an experienced and credentialed echocardiographer (anesthesiologist or cardiologist) who is not involved in the direct anesthetic care of the patient perform the TEE.

Hemodynamic Management

Precise blood pressure control is required to reduce the wall stress on the apical purse-string suture. Specific blood pressure targets change according to the specific steps of the procedure and may vary by institution. If needed, short-acting intravenous medications should be considered. Short-acting calcium
channel blockers, such as nicardipine or clevidipine, are good options because they are not associated with the same degree of reduction in preload as seen with other agents. It is important for the anesthesiologist to recognize that, despite relieving the patient’s outflow obstruction with a new valve, cardiac function initially may be compromised. Pacing can induce ventricular arrhythmias that necessitate supportive cardiac massage and/or cardioversion. 

Pain Management

Adequate analgesia is required not only for patient comfort, but also is essential for facilitating early extubation. Alternatives to opiates, such as intravenous acetaminophen, should be considered. Medications that impair platelet function or impair renal function probably should be avoided. Epidural catheters have been reported in TA-TAVRs. One institution published their use of epidurals to help address the postoperative thoracotomy pain and facilitate extubation in this frail group of patients and observed improved 30-day and 1-year mortality. 

Alternative Access Routes

The high risk and cost of TA-TAVRs have motivated physicians to investigate alternatives, such as the transaortic, subclavian/axillary, carotid, and the brachiocephalic approach for patients with suboptimal iliofemoral artery anatomy. The published experience with these alternative techniques comes predominantly from single-center reports with a limited number of patients, in contrast to the TA-TAVR and the TF–TAVR, for which there are multiple large national and international registries. The transaortic approach uses an upper ministernotomy to access the aortic valve. The technique has shown some initial benefits with regard to respiratory and postoperative bleeding, with improved ICU length of stay in selected patients.
CONCLUSION

The explosive growth of TAVR has created a “clinical data conundrum,” rendering meaningful comparisons of outcomes between trials problematic, because early studies used different definitions for endpoints.38 Still, the consistency of the available reports would suggest that the difference between the two procedures is much deeper than simply access points. Patients undergoing TA-TAVR appear to represent a more extreme subgroup of individuals with a higher disease burden than patients presenting for TF-TAVRs. The procedure itself is more invasive and has a unique set of risks. From the perspective of resource management, a review of the PARTNER trial using quality-adjusted life-years showed that TA-TAVRs are less cost-effective than TF-TAVRs relative to surgical AVR because of greater hospital resource use and poorer short-term outcomes.39 From an anesthesiologist’s more clinically focused perspective, these cases are at least as complex as SAVRs. The fragility of TA-TAVR patients demands fastidious attention to a myriad of details, because such patients tend not to recover from either surgical or anesthesia misadventures.73 A thorough understanding of the procedural steps involved in TA-TAVRs, their physiologic consequences and possible complications, allows the anesthesiologist to be proactive in the care of these patients.89

APPENDIX A. SUPPLEMENTARY INFORMATION

Supplementary data associated with this article can be found in the online version at doi:10.1053/j.jvca.2013.11.006.

REFERENCES

Predicted Risk of Mortality score in patients implanted with the CoreValve ReValving system—A Bern-Rotterdam Study. Am Heart J 159:323-329, 2010


outcome. Results from the German transcatheter aortic valve interventions registry. Heart 97:899-906, 2011


