

# Transcatheter Aortic Valve Implantation: Anesthetic Considerations

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Aortic valvular stenosis remains the most common debilitating valvular heart lesion. Despite the benefit of aortic valve (AV) replacement, many high-risk patients cannot tolerate surgery. AV implantation treats aortic stenosis without subjecting patients to sternotomy, cardiopulmonary bypass (CPB), and aorta cross-clamping. This transcatheter procedure is performed via puncture of the left ventricular (LV) apex or percutaneously, via the femoral artery or vein. Patients undergo general anesthesia, intense hemodynamic manipulation, and transesophageal echocardiography (TEE).

To elucidate the role of the anesthesiologist in the management of transcatheter AV implantation, we review the literature and provide our experience, focusing on anesthetic care, intraoperative events, TEE, and perioperative complications.

Two approaches to the aortic annulus are performed today: transfemoral retrograde and transapical antegrade. Iliac artery size and tortuosity, aortic arch atheroma, and pathology in the area of the (LV) apex help determine the preferred approach in each patient.

A general anesthetic is tailored to achieve extubation after procedure completion, whereas IV access and pharmacological support allow for emergent sternotomy and initiation of CPB. Rapid ventricular pacing and cessation of mechanical ventilation interrupts cardiac ejection and minimizes heart translocation during valvuloplasty and prosthesis implantation. Although these maneuvers facilitate exact prosthesis positioning within the native annulus, they promote hypotension and arrhythmia. Vasopressor administration before pacing and cardioversion may restore adequate hemodynamics.

TEE determines annulus size, aortic pathology, ventricular function, and mitral regurgitation. TEE and fluoroscopy are used for positioning the introducer catheter within the aortic annulus. The prosthesis, crimped on a valvuloplasty balloon catheter, is implanted by inflation. TEE immediately measures aortic regurgitation and assesses for aortic dissection. After repair of femoral vessels or LV apex, patients are allowed to emerge and assessed for extubation.

Observed and published complications include aortic regurgitation, prosthesis embolization, mitral valve disruption, hemorrhage, aortic dissection, CPB, stroke, and death.

Transcatheter AV implantation relies on intraoperative hemodynamic manipulation for success. Transfemoral and transapical approaches pose unique management challenges, but both require rapid ventricular pacing, the management of hypotension and arrhythmias during beating-heart valve implantation, and TEE. Anesthesiologists will care for debilitated patients with aortic stenosis receiving transcatheter AV implantation.

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**W**ith 50,000 procedures performed annually in the United States, aortic valve replacement (AVR), secondary to calcific aortic stenosis,<sup>1</sup> remains the most

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A contributing author, Susheel Kodali, is a coinvestigator in the Revival Trial, which is a prospective, multicenter, nonrandomized feasibility study of the Cribier-Edwards aortic bioprosthetic valve for the treatment of critical aortic stenosis using either a transapical or transfemoral delivery approach. This manuscript does not address the results or methods of the Revival Trial.

common valvular heart surgery.<sup>2</sup> Valve replacement alleviates symptoms and reduces valve mean gradients to 20 mm Hg or less, dependent upon prosthesis and ventricular function.<sup>3</sup> AVR increases 3-yr life expectancy by 4.1-fold<sup>4</sup> but conveys risks of stroke, renal failure, transfusion, and death.<sup>5</sup> Percutaneous valvuloplasty, initially developed to treat valve stenosis less invasively, only provides temporary gradient

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and symptom relief.<sup>6</sup> Because stenosis typically returns within 6 mo following valvuloplasty,<sup>7</sup> valve replacement has remained the only definitive therapy.<sup>8,9</sup> Despite the clear benefits of AVR for patients with stenotic valves,<sup>4</sup> open AVR surgery has an associated perioperative mortality of 4%–18%, dependent on patient comorbidities.<sup>10,11</sup> Consequently, open-heart surgery is often withheld from high-risk patients, despite the dismal prognosis of symptomatic aortic stenosis.<sup>12</sup> As our population ages, aortic stenosis prevalence and age-related comorbidities will increase.<sup>13</sup>

A less invasive management for aortic valvular stenosis might benefit this patient population. Cribier et al.<sup>14</sup> first described transcatheter aortic valve (AV) implantation after transcatheter valvuloplasty in 2002. He chose to approach the AV via femoral venous cannulation, transatrial septal puncture, and antegrade deployment through the left ventricular outflow tract (LVOT) by way of the mitral valve. Since then, and more popularly, prosthetic AVs have been deployed retrograde, from the aorta, via cannulation of the femoral artery and antegrade, by puncture of the left ventricular (LV) apex via a small left thoracotomy.<sup>15</sup>

Two devices are available. The Cribier-Edwards prosthesis is Food and Drug Administration approved, in trials at various North American and European centers, and is described in detail here within. The CoreValve<sup>®</sup> device (Irvine, CA) is a trileaflet porcine pericardial tissue valve mounted in a self-expanding nitinol stent and is in trials outside of the United States. Although long-term viability of these procedures has not been demonstrated, several small series have been reported with largely successful results.<sup>16–21</sup> We wish to review our experience with these procedures, focusing on anesthetic considerations.

## DESCRIPTION OF THE PROCEDURE

The decision to use transfemoral arterial or transapical approach is based on assessment of aortic and iliac artery size and pathology and the presence of pathology in the region of the LV apex, such as apical aneurysm, pericardial disease, previous left thoracotomy, or chest radiation.

The theoretical advantages of the transfemoral approach include avoidance of a thoracotomy and manipulation of the apex of the LV. Theoretical advantages of the transapical approach include avoidance of peripheral vascular and aortic complications and more direct control during positioning and deployment of the prosthesis. Both approaches utilize the same valve and delivery system. The Cribier-Edwards prosthesis is a pericardial xenograft available in two sizes that contains three tissue cusps mounted on a stainless steel vascular stent (Edwards Lifesciences, Irvine, CA). Once deployed, the valve measures 14 or 16 mm in length and 23 or 26 mm in diameter (Fig. 1). For introduction, positioning, and deployment, the valve is crimped onto a balloon

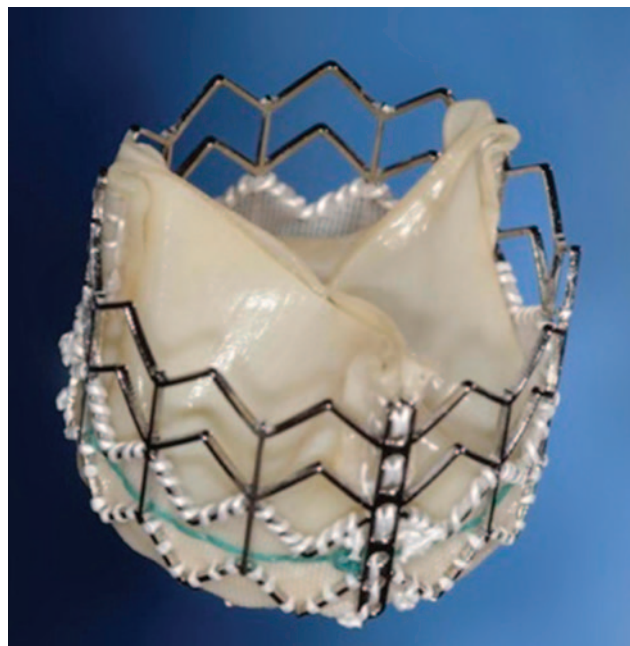


Figure 1. Cribier-Edwards transcatheter bioprosthesis. Reprinted from Walther et al.<sup>22</sup> with permission from Elsevier.



Figure 2. Valve prosthesis crimped onto a balloon-tipped catheter.

tipped catheter and inserted through a 24F or 26F introducer (Fig. 2). Postdeployment, the prosthesis stents the native aortic leaflets open permanently. The valve stent prosthesis assumes all valvular function.

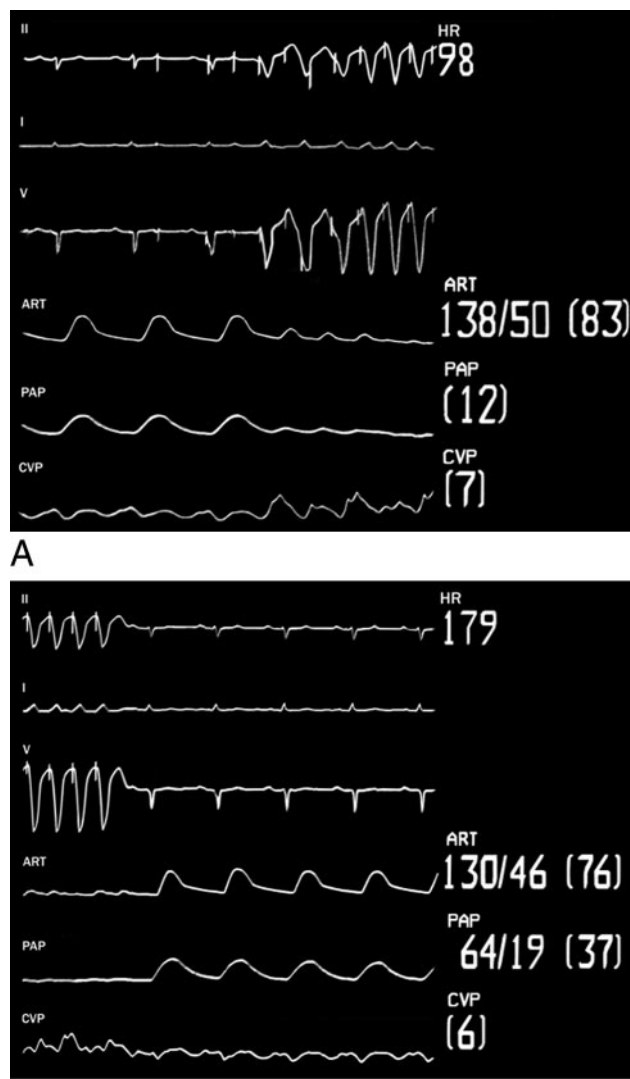
Implantations are performed in a hybrid operating room with the capabilities of both a traditional cardiac

operating room and an angiographic suite. The left-sided femoral artery and vein are accessed percutaneously with standard diagnostic vascular introducers to provide for hemodynamic measurements, continuous monitoring, transvenous right ventricular pacing, injection of contrast media, and vascular access for emergent initiation of femoral-femoral cardiopulmonary bypass (CPB). Right and left heart diagnostic catheterization is performed, including measurement of the AV gradient and aortic root contrast injection. The aortic annulus must measure between 18 and 25 mm for use of the Edwards bioprosthesis.

Detailed operative descriptions of the venous transfemoral antegrade, arterial transfemoral retrograde, and transapical ventricular approach have been published in the cardiology and surgical literature.<sup>21–23</sup> We will focus on the aspects of particular importance to the anesthesiologist.

### Retrograde Transfemoral Approach

The right femoral artery is accessed percutaneously with a 12F sheath, and a 20–23 mm balloon tipped valvuloplasty catheter is advanced into the AV annulus. Rapid ventricular pacing at 200 bpm creates a low cardiac output state, as indicated by the abrupt fall in systemic pulse pressure (Fig. 3A), and temporary interruption of mechanical ventilation limits respiratory translocation of the heart, both performed to limit displacement of the balloon during inflation. Inflation of the balloon tipped catheter within the AV annulus performs the valvuloplasty. Without rapid ventricular pacing and temporary cessation of cardiac ejection, significant distal movement of the catheter can occur during balloon inflation (Video 1; please see video clips available at [www.anesthesia-analgesia.org](http://www.anesthesia-analgesia.org)). After valvuloplasty, a process that takes approximately 10 s, rapid ventricular pacing is terminated, cardiac output is restored (Fig. 3B), and ventilation resumed. The AV gradient is measured again and aortic regurgitation (AR) assessed with transesophageal echocardiography (TEE) and aortic root contrast injection. The 12F sheath in the right femoral artery is then exchanged for the 24F or 26F (depending on prosthesis size) device introducer sheath. Using fluoroscopic guidance, the prosthetic valve, on the deployment catheter, is advanced over a guidewire and positioned within the AV annulus. After rapid ventricular pacing is reinitiated and ventilation paused, the prosthetic valve is deployed by inflating the catheter's balloon (Fig. 4, Video 2; please see video clips available at [www.anesthesia-analgesia.org](http://www.anesthesia-analgesia.org)). Rapid ventricular pacing is promptly terminated and ventilation resumed. Valve deployment takes 10–15 s. Prosthetic valve position and function, blood flow, and ventricular function are immediately assessed with fluoroscopy and TEE (Figs. 5A and B, Videos 3 and 4; please see video clips available at [www.anesthesia-analgesia.org](http://www.anesthesia-analgesia.org)). Postimplantation diagnostic heart catheterization is performed, and the



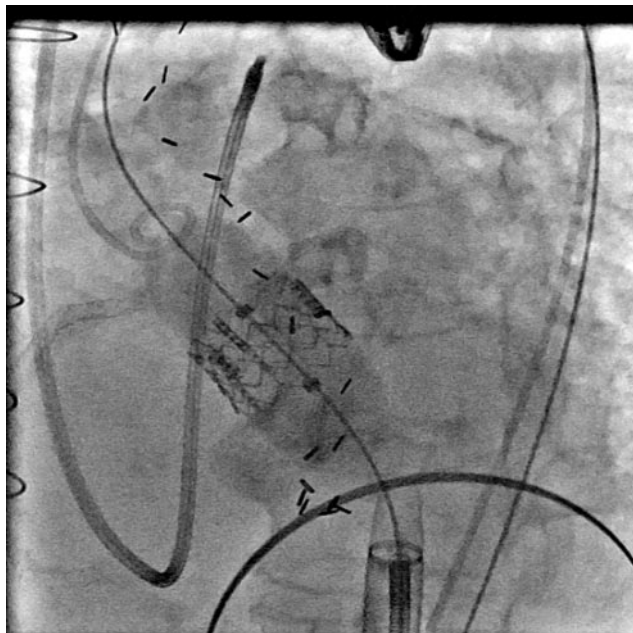
**Figure 3.** (A) Initiation of rapid ventricular pacing. (B) Cessation of rapid ventricular pacing.

delivery system is removed from the right femoral artery.

The large device introducer sheath is removed under direct vision, to allow suturing and patch repair of the femoral arteriotomy. This is often the most time-consuming aspect of the transfemoral procedure.

### Antegrade Transapical Approach

A cardiac surgeon performs a left anterolateral mini-thoracotomy, approximately 10 cm long, in the fifth intercostal space, over the LV apex. After opening the pericardium and placement of epicardial pacing wires, purse-string sutures are placed in the apex of the LV. The LV apex is pierced with a hollow needle between the purse-string sutures, and a guidewire advanced through the LV and across the AV into the ascending aorta by fluoroscopic and TEE guidance, taking care not to ensnare the mitral apparatus. A 16F introducer sheath is placed over the wire and positioned in the LVOT; through which the balloon tipped valvuloplasty catheter is advanced antegrade across



**Figure 4.** Posterior-anterior fluoroscopic image of bioprosthetic valve deployment by balloon inflation.

the AV. Valvuloplasty is performed as with the transfemoral approach, and the AV gradient and regurgitation are assessed. The valvuloplasty sheath in the apex is exchanged for a 33F device introducer sheath and the prosthetic valve deployed as with the transfemoral approach (Fig. 6 and Video 5; please see video clips available at [www.anesthesia-analgesia.org](http://www.anesthesia-analgesia.org)). The device and introducer are removed from the apex, as the purse string sutures are tied down. After intercostal nerve blockade with 0.25% bupivacaine, the surgeon closes the thoracotomy in standard fashion.

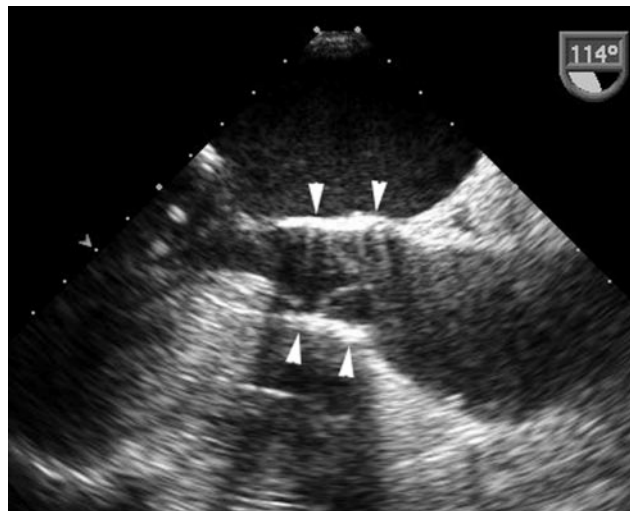
## RISKS

Complications reflect both the access route to the AV and the valvular procedure itself.

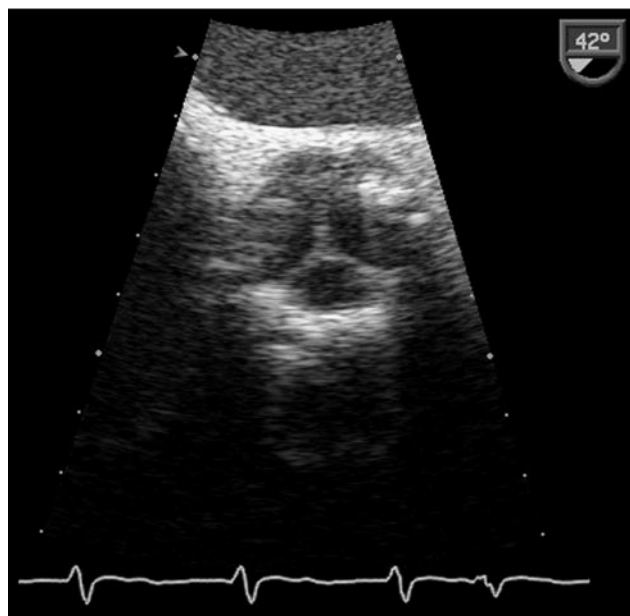
Inherent to the transapical route, minithoracotomy and LV puncture carry risks of LV rupture and postthoracotomy respiratory debilitation.

Inherent to the transfemoral route, large bore vascular cannulation presents surgical challenges upon catheter removal. Femoral and iliac artery damage is common, with variable degrees of hemorrhage.

Irrespective of approach, complications of valvuloplasty, valve implantation, and aortic instrumentation include stroke and aortic dissection. Ascending aortic dissection, a devastating complication, requires open repair. In one case report, iliac vascular tissue, transported to the aortic arch by the device catheter, resulted in fatal embolic stroke.<sup>24</sup> There are no specific mechanisms to limit embolic debris during these maneuvers. As mentioned in the "role of TEE," the presence of high-grade aortic atheroma supports utilization of the transapical approach. Calcification of the native valve provides a strong structural contact



**A**

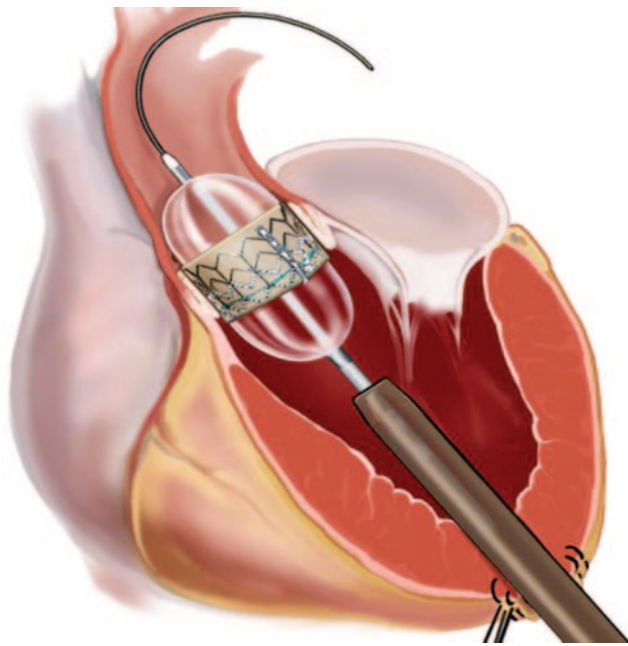


**B**

**Figure 5.** Transesophageal echocardiography (TEE) mid-esophageal aortic valve long-axis (A) and short-axis (B) views of the deployed prosthetic valve (arrowheads).

for prosthesis implantation but may potentiate perivalvular AR. These perivalvular leaks, as discussed in the TEE and results sections, occurred frequently, with variable severity and effect.

Valve embolization has been experienced during initial attempts with the procedure but was not observed in our series. Management of this complication requires repositioning of prosthesis, implantation of an additional valve prosthesis, or emergent sternotomy, CPB, aortic cross-clamping, and aortotomy to remove the embolized valve and perform open AVR.<sup>25</sup> As with most developing procedures, a learning curve exists. Practitioners become more precise and successful with valve sizing, positioning, and appropriate strength of implantation, after the first few procedures.<sup>23</sup> Ensuring that the majority of the valve rests on the ventricular side of the annular plane



**Figure 6.** Schematic of transcatheter aortic valve implantation. The prosthesis is implanted within the native annulus by balloon inflation. Reprinted from Walther et al.<sup>22</sup>, with permission from Elsevier.

during implantation remains an important learning point.

Theoretical complications, which have neither been experienced nor reported, include obstruction of coronary ostia by a malpositioned prosthesis and interference with mitral valve function during catheter positioning or after valve deployment by impingement on the annulus fibrosus.

The complication rates of stroke, cognitive dysfunction, arrhythmias, and respiratory insufficiency, poor outcomes typically associated with cardiac surgery, have yet to be determined. Radiocontrast exposure, particularly in patients with preexisting renal disease, may worsen the propensity for acute kidney injury.

## ANESTHETIC CONSIDERATIONS

As a consequence to TEE and the surgical intervention typically required for transcatheter valve implantation, all patients at our institution receive general anesthesia with endotracheal intubation. Our approach to the anesthetic care is similar to that of a high risk conventional AV replacement, except that we tailor the narcotic and benzodiazepine administration to allow for emergence and extubation at the end of the procedure. After completion, patients are transferred to a coronary care unit or cardiac surgical intensive care unit (ICU).

A radial artery catheter is placed for dedicated continuous systemic blood pressure monitoring before anesthetic induction. External defibrillating pads and standard American Society of Anesthesiologist monitors are applied. We do not employ thoracic epidural

anesthesia, regardless of the potential benefits of intraoperative pain control and postoperative respiratory recovery, because the thoracotomy is small and systemic anticoagulation begins before surgery and continues postoperatively. Patients are loaded with clopidogrel, 300 mg, before the procedure and then continued at a daily dose of 75 mg for 6 mo. Patients are started on aspirin, 325 mg, once daily, postoperatively. Intraoperatively, patients receive 5000 U of heparin before valvuloplasty and then, as needed, to maintain an activated coagulation time >250 s.

After induction of general anesthesia, a single-lumen endotracheal tube is placed, and the TEE is probe positioned in the patient's esophagus. Despite the left thoracotomy performed during the transapical approach, isolated right lung ventilation with a double-lumen endotracheal tube is not necessary for ventricular apical exposure. Consequently, we avoid exchanging the double-lumen tube to a single-lumen tube at the end of the procedure, in the event that mechanical ventilation should be continued postoperatively. A multilumen vascular introducer sheath with a large infusion port is placed in a central vein, followed by insertion of a pulmonary artery catheter. Infusion pumps are connected. In addition to the vasopressor support often given to anesthetized patients with severe aortic stenosis, vasopressor boluses are commonly given just before periods of rapid ventricular pacing. The consequent increase in vascular tone limits the drop in systemic blood pressure during the marked reduction of cardiac output, maintaining coronary perfusion during and after inflation of the device balloon. After deployment of the valve and termination of rapid ventricular pacing, cardiac rate and rhythm and arterial blood pressure typically return to baseline (Fig. 3B), but bolus administration of a vasopressor or direct current defibrillation via cutaneous defibrillator pads may be required to restore stable hemodynamics. It remains important to assess each patient's hemodynamic response to rapid ventricular pacing initiation and termination during each of the three pacing periods. The first brief pacing period, during pacing wire capture testing, is less disruptive than the second pacing period, which is longer and includes complete interruption of LV ejection during valvuloplasty, which remains still less disruptive than the third pacing period, which includes more prolonged interruption of LV ejection, during prosthesis deployment. We examine TEE and arterial, central venous, and pulmonary artery waveforms carefully during these periods. If initial pacing wire testing or valvuloplasty creates severe or prolonged hypotension during and after rapid ventricular pacing, the patient may require a larger bolus of a vasopressor before the subsequent pacing period. Key points are summarized in Table 1.

Considerable acute blood loss may occur during removal of the device deployment sheath from the femoral artery or the LV apex.

**Table 1.** Primary Anesthetic Goals

Avoid tachycardia and reduction of coronary filling pressure during anesthetic induction
Maintain systemic perfusion pressure during rapid ventricular pacing
Limit cardiac ejection and heart translocation during valve implantation
Extubate safely upon procedure completion

## ROLE OF TEE

All patients receive TEE monitoring during valve implantation. The TEE probe is inserted after endotracheal intubation and removed at the end of the procedure. As with open AVR, one anesthesiologist can perform TEE and manipulate anesthetic and vasoactive drugs during the procedure. However, we typically have two anesthesia providers and often a cardiologist. A comprehensive baseline examination is performed to confirm the diagnosis, assess baseline ventricular function, and detect associated valvular lesions such as mitral and tricuspid regurgitation. Measurements of the AV annulus, LVOT, and proximal aorta are made from the mid-esophageal AV long-axis view to assist size selection of the prosthetic valve and confirm feasibility of successful implantation. The annulus must be between 18 and 21 mm or 22 and 25 mm in diameter, for use of the 23 or 26 mm Edwards' prosthesis, respectively. The ascending aorta and arch are evaluated for the presence of atheroma. Severe mobile plaque supports utilization of the transapical approach, which avoids manipulation of large catheters in the aorta. Unlike the self-expanding CoreValve, the Edwards' prosthesis seats solely within the native annulus, eliminating ascending aorta dilation as a contraindication.

TEE and arterial waveform observation are used to verify the lack of ventricular contraction and peripheral arterial pulse-waves during testing of rapid ventricular pacing.

Although fluoroscopy is the primary imaging modality utilized during positioning of the crimped catheter-seated prosthesis within the native annulus, we confirm appropriate positioning with the AV long-axis view. Valve function depends on exact positioning of the deployment catheter and valve. The 14 or 16-mm long Edwards prosthesis relies on traction with the native annulus for postdeployment stability. Although the prosthesis must be positioned distal enough to permanently stent open the native AV cusps, slightly more than half of the prosthesis should remain on the ventricular side of the AV annulus. Deployment of the apparatus at the level of the sinuses of valsalva is too distal, may lead to AR, and risks valve embolization. The catheter is positioned so that the proximal end of the valve sits 2–3 mm proximal to the origin of the anterior mitral leaflet on AV long-axis view. Because temporary rapid ventricular pacing appropriately abolishes cardiac ejection,

deployment of the valve results in minimal movement of the valve with relationship to the annulus. Although one group noticed 2–4 mm of distal movement during deployment,<sup>26</sup> we found postdeployment valve location consistent with predeployment catheter position. Both TEE and fluoroscopy can be used for exact catheter positioning. It may be necessary to withdraw the TEE probe to the level of the aortic arch to prevent obstruction during fluoroscopic imaging.

After valve implantation, short and long-axis AV and ascending aorta TEE views assess the prosthesis position within the AV annulus and the integrity of the ascending aorta. Transgastric and mid-esophageal 4-chamber and 2-chamber views assess ventricular function, wall motion, and mitral valve function. Expected findings include unchanged ventricular function, unchanged or decreased LV end-systolic and end-diastolic volume, unchanged or reduced mitral regurgitation, intact ascending aorta, mild AS, and variable AR. Color flow Doppler assesses AR. Severity is graded by examining the vena contracta, width of regurgitant jet within the LVOT, and depth of regurgitant jet into the LV.<sup>8</sup> TEE allows the accurate differentiation between transvalvular and perivalvular AR, a distinction difficult to make by fluoroscopy and aortic root contrast injection. (Videos 6–9; please see video clips available at [www.anesthesia-analgesia.org](http://www.anesthesia-analgesia.org)) Reinflating the deployment balloon within the prosthesis, further expanding the valve within the annulus, is often employed for treatment of perivalvular AR. One group utilized this technique in 36% of their transcatheter AV implantations.<sup>25</sup> Significant transvalvular AR suggests over expansion of the prosthesis, which may require deployment of a second prosthetic valve within the first (Fig. 7).

Although the aortic valvular prosthesis sits within the aortic annulus, remaining in tight contact with the mitral annulus via the annulus fibrosis, prosthesis implantation does not lead to deleterious changes in mitral function. In fact patients may experience less mitral regurgitation after deployment, secondary to reduced aortic valvular gradient and the consequent decrease in ventricular systolic pressures and volume.

As with any major cardiac intervention, TEE remains invaluable for monitoring intraoperative cardiac function (Table 2). As with open AVR, relief of significant ventricular outflow obstruction increases ventricular ejection and alters cardiac filling. TEE aids in directing fluid resuscitation and vasopressor and inotrope administration.

## SINGLE-CENTER RESULTS

After institutional review board approval, we examined all patients enrolled in the Revival Trial, within our institution. Columbia University Medical Center is a study site for the Revival Trial, a multicenter, prospective, nonrandomized, feasibility study that examines transcatheter AV implantation in high-risk patients, using the Cribier-Edwards prosthesis.



**Figure 7.** Posterior-anterior fluoroscopic image showing a second prosthesis deployed within the first prosthesis, secondary to severe central aortic insufficiency after deployment of the first prosthesis. Note the transesophageal echocardiography (TEE) probe, transapical introducer sheath, PA catheter, ascending aorta, and aortic pigtail catheter.

**Table 2.** TEE Assessment Goals

Preimplantation
AV annular size
Ascending aortic atheroma
Postimplantation
Prosthesis position and orientation
Aortic regurgitation (central versus perivalvular)
LV size and function (rule out ischemia)
Mitral regurgitation
Aortic dissection

The Revival Trial has institutional review board approval and all patients gave informed, written consent before participation. Enrollment criteria for the Revival Trial included calculated AV area  $<0.7 \text{ cm}^2$  within 6 mo of the procedure, age  $\geq 70$  yr, associated comorbid factors such that the surgeon and cardiologist coprinciple investigators agreed that the predicted risk of operative mortality was at least 15%, and a minimum Society of Thoracic Surgery (STS) score of 10.

Between February 8, 2006 and March 22, 2007, 36 study patients underwent transcatheter prosthetic AV implantation, 29 by transfemoral arterial approach and seven by transapical approach. Relevant clinical information is summarized for each patient in Table 3. Median (interquartile range) STS score predicted mortality was 10% (6.3, 17.8),<sup>21</sup> and EuroSCORE logistic predicted perioperative mortality was 31% (21.5, 44).<sup>27</sup> Two thirds of the patients were female. The median (IQR) age was 84 (78, 89) yr.

The transfemoral approach cohort had a median (IQR) procedure duration of 5.5 (4.5, 6.5) h. The

transapical approach cohort had a median (IQR) procedure duration of 4.3 (3.8, 4.5) h.

In our experience, 31 of 36 patients received some vasopressor support during the procedure, but only 5 of 36 received inotropic drugs. For increasing systemic vascular resistance before periods of rapid ventricular pacing, phenylephrine (200–400  $\mu\text{g}$ ) or norepinephrine (4–16  $\mu\text{g}$ ) was adequate. After these periods, no patients failed to return to their preprocedure cardiac rhythm or were left with severe prolonged hypotension.

The median (IQR) estimated blood loss was 250 (100, 700) mL for the transfemoral group and 200 (100, 500) mL for the transapical group. Fifty-two percentage of the transfemoral patients and 43% of the transapical patients received blood products during the procedure.

Postimplantation AR was common. As assessed by intraoperative TEE, all patients had at least trace central AR, and perivalvular AR ranged from none to severe. Four of the 36 patients had moderate perivalvular AR, and one patient had severe perivalvular AR after prosthesis implantation.

Aortic stenosis in all patients was reduced from severe to mild after balloon valvuloplasty and prosthesis implantation.

Twenty (71%) of the transfemoral patients and three (43%) of the transapical patients met extubation criteria at the end of the procedure. One transapical patient required emergency CPB to control bleeding and repair the LV apex, after removal of the device introducer and securing of the purse string.

We found femoral and iliac artery damage common, with variable degrees of hemorrhage. Twenty-five of the 29 transfemoral patients underwent open surgical patch repair of the arterial access site. This procedure became standard after the first few transfemoral procedures. Three of these patients had femoral/iliac transections requiring ilio-femoral bypass with a synthetic graft, and one patient had their aortic procedure aborted because of iliac artery injury, necessitating immediate major repair in the vascular suite. One of the seven transapical patients underwent patch repair of the left femoral artery access site.

One of the transfemoral procedures was aborted because of persistent kinking of the delivery introducer resulting in inability to properly position the prosthesis within the native valve.

Irrespective of approach, upon valvuloplasty balloon inflation, two patients experienced acute aortic dissection. In one of these patients, this dissection was complicated by severe aortic valvular insufficiency, unstable hemodynamics, and emergent sternotomy, initiation of CPB, and open AV and ascending aorta replacement. This patient died postoperative day (POD) 3 secondary to heart failure. The other patient's acute aortic dissection encompassed the left main coronary artery and occluded all three aortic arch vessels, leading to death on POD 1.

Four of 36 patients died in our series, two previously mentioned as a consequence of aortic dissection.

Table 3. Summary of Individual Patients for Transcatheter AV Implantation

Patient no.	Age (yr)	Sex	Euro SCORE (%)	STS score (%)	Duration (h)	EBL (mL)	IV Fluids (mL)	Blood products	Inotropic drugs	Vaso-pressors	CPB	Post-AR grade	Extubated	Comments
<b>Transfemoral</b>														
1	92	M	21	10	4.0	100	1000	None	Eph	Ph	No	0	In OR	
2	85	F	21	6	4.0	50	2000	None	None	NE	No	0	In OR	Fem artery repair
3	86	F	31	17	5.5	600	2000	None	None	NE	No	0	POD 5	Fem artery repair
4	78	F	33	9	8.5	300	4000	2u prbc	None	NE	No	2+	In OR	Bilat fem artery dissection with repair
5	73	M	17	4	5.0	50	2000	None	None	Ph	No	0	In OR	
6	91	F	28	10	4.5		2000	None	None	Ph	No	1+	In OR	Fem artery repair
7	84	F	50	23	7.0	700	4000	3u prbc	None	Ph	No	0	In OR	Fem/iliac artery repair
8	83	F	37	11	3.8	250	800	None	None	NE	No	1+	In OR	Fem artery repair; right MCA CVA
9	75	M	30	9	9.5	1600	4000	4u prbc	None	Ph, NE	No	N/A	In OR	Iliac artery rupture; percAVR aborted; to OR emergently for vascular surgery
10	75	F	14	4	5.5	250	3000	None	None	Ph	No	0	POD 0	Fem artery repair
11	92	F	52	23	12.0	1500	4000	7u prbc, 18u plts, 3u ffp, 4u cell saver, 500 mL cryo	Eph, Epi, M	NE, V	Yes	N/A	Not	Aortic dissection; percAVR aborted; to OR emergently for open AVR and Ao repair, died POD 3
12	77	F	10	4	4.5	150	1000	None	None	Ph	No	0	In OR	Fem artery repair
13	73	F	8	4	6.5	2000	3600	8u prbc, 4u ffp	Dobut	NE	No	1+	POD 16	Iliac transection, ilio-fem bypass
14	89	M	39	12	5.5	50		None	None	Ph	No	1+	In OR	Fem artery repair
15	95	F	26	27	7.0	300	1000	3u prbc	None	NE, V	No	1+	POD 1	Iliac transection, ilio-fem bypass
16	79	F	30	16	7.5	700	2000	4u prbc	None	None	No	0	In OR	Iliac artery patch repair
17	82	F	31	9	5.0	50	1550	1u prbc	None	Ph	No	0	In OR	Fem artery repair
18	89	M	25	10	4.5	250	1500	None	None	NE, V	No	0	In OR	Fem artery repair
19	83	F	14	6	5.5	100	1700	None	None	NE	No	1+	In OR	Fem artery dissection with normal flow
20	87	M	46	19	4.0	75	1600	None	None	NE	No	0	In OR	Fem artery repair
21	91	F	28	21	4.5	50	2100	6u plts	None	None	No	1+	In OR	Fem artery repair; SAH intraop or POD 0
22	97	M	49	29	6.0	750	1500	2u prbc	None	None	No	2+	In OR	Fem artery repair & angioplasty
23	84	M	40	11	4.0	100	800	None	None	NE	No	1+	In OR	Fem artery repair
24	72	M	10	4	6.5	2000	3000	5u prbc	None	NE	No	0	POD 3	Iliac avulsion, ilio-fem bypass
25	70	M	20	7	5.5		3000	3u prbc	Epi	NE, V	No	N/A	Not	Aortic dissection, percAVR aborted; died POD 1
26	82	F	36	5	4.5	200	600	None	M	NE, V	No	1+	In OR	Fem artery repair
27	91	F	32	18	5.5	100	2000	2u prbc	None	None	No	1+	In OR	Fem artery repair
28	82	F	45	10	6.0	500	2000	4u prbc	None	Ph	No	N/A	POD 0	Percavr aborted due to persistant kinking of sheath; fem artery repair
29	76	F	47	24	6.0	700	3250	2u prbc	Epi	NE, V	No	0	In OR	Postinduction vascular collapse; fem artery repair
Median	83	66% F	30	10	5.5	250	2000	52%	21%	86%	3%		72% in OR	
25 quartile	76.5		20.5	6.0	4.5	100	1500							
75 quartile	90.0		39.5	18.5	6.5	700	3000							
<b>Transapical</b>														
1	88	F	23	24	4.5	100	2000	3u prbc	None	Ph	No	1+	POD 1	Died POD 41 of pneumonia
2	84	F	27	17	3.8	100	1000	None	None	NE	No	0	POD 1	
3	84	F	59	11	5.0	500	2000	4u prbc	M	NE	Yes	1+	POD 0	Apical bleeding requiring CPB to control
4	86	F	68	15	4.3	500	800	1u prbc	None	Ph	No	0	In OR	Fem artery repair
5	80	M	41	4	3.5	200	1000	None	None	None	No	2+	In OR	
6	89	F	35	9	4.0	200	1000	None	None	NE	No	4+	In OR	To OR POD 1 for AVR, MVR, CABG; died POD 41
7	88	M	61	10	4.3	200	1000	None	None	NE	No	2+	POD 1	
Median	86	71% F	41	11	4.3	200	1000	43%	14%	86%	14%		43% in OR	
25 quartile	84.0		26.8	9.0	3.8	100	1000							
75 quartile	88.0		61.0	17.0	4.5	500	2000							

STS = the Society of Thoracic Surgeons predicted rate of mortality; EBL = estimated blood loss; CPB = cardiopulmonary bypass; AR = aortic regurgitation; OR = operating room; fem = femoral; prbc = packed red blood cells; ffp = fresh frozen plasma; plts = platelets; cryo = cryoprecipitate; Eph = ephedrine; Epi = epinephrine; M = milrinone; Dobut = dobutamine; Ph = phenylephrine; NE = norepinephrine; V = vasopressin; POD = postoperative day; N/A = not applicable secondary to aborted procedure.

Another patient had severe postprocedure perivalvular AR and underwent open AVR, mitral valve replacement, and coronary artery bypass grafting on POD 1. After a protracted ICU course, this patient died on POD 41. And finally, a fourth patient underwent an uncomplicated operative course, was transferred to the step-down unit on POD 4, but languished with dyspnea and weakness for 30 days, before readmission to the ICU, and eventual death, also on POD 41, secondary to pneumonia and sepsis.

## DISCUSSION

Transcatheter AV implantation has developed out of an interest and a need for ameliorating aortic valvular disease, specifically degenerative calcific valvular stenosis in elderly high-risk patients. In a recent review, Lung et al.<sup>28</sup> found that one third of patients who could benefit from AVR do not receive such treatment because of advanced age or significant comorbidities. Our anesthetic experiences have revealed this procedure to be feasible, even with a high-risk population. Transcatheter valve implantation might provide these high-risk surgical candidates the opportunity for definitive treatment of their aortic stenosis.

Our small case series had a perioperative mortality of 2/36 (5.6%) and an in-hospital mortality of 4/36 (11.1%). This perioperative mortality percentage is comparable with that of open surgery, even though the predicted STS and EuroSCORE logistic perioperative mortality of our patient cohort was higher. Our cohort revealed significant differences between the projected risks of the STS scoring system and the EuroSCORE logistic system. These differences, however, are consistent with other projected risk reports of AVR in high-risk patients and point to concerns of the validity of these preoperative risk-stratifying systems specific to this patient population. In a retrospective analysis of 638 patients whom underwent isolated AVR, Dewey et al.<sup>29</sup> found significant bias similar to ours with respect to STS and EuroSCORE systems, particularly with regard to high-risk patients. For proper analysis of outcomes with regard to risk stratification, of different transcatheter approaches, and compared with open AVR, randomized controlled trials are needed and underway (The Partner Trial: Placement of Aortic Transcatheter Valve; [clinicaltrials.gov](http://clinicaltrials.gov) identifier NCT00530894).

Because our series did not randomize or match patients between the two approaches utilized, only a few differences between the transfemoral and the transapical implantations will be discussed. Transfemoral implantation procedures had a significantly longer operative time. Transfemoral procedure patients also tended to have more blood loss. Both of these differences are likely due to the peripheral vasculature injury and meticulous repair after removal of the femoral 24F–26F introducer sheath. And finally, transfemoral patients tended to be extubated earlier than transapical patients. Although

speculative, avoiding the mini-thoracotomy inherent to the transapical approach could provide for prompt extubation and less postoperative respiratory morbidity.

The current technology and procedure necessitates general anesthesia, endotracheal intubation, and TEE. TEE provides specific benefits in valve sizing, prosthesis positioning, postimplantation evaluation, cardiac assessment, and anesthetic management. As also demonstrated with the CoreValve prosthesis,<sup>30</sup> TEE shows excellent visual agreement with fluoroscopy. TEE facilitates the detection and management of procedure-related complications. In particular, significant perivalvular AR is often treated by additional balloon dilation of the prosthetic AV. Despite these benefits, some centers are performing transcatheter AV implantation with monitored anesthesia care and without TEE.<sup>20</sup> This could be advantageous considering the mortality and morbidity risk of general anesthetic induction in patients with significant aortic stenosis.<sup>31</sup> However, as a larger range of devices become available, TEE will perform an even more important function in matching patient anatomy with prosthesis selection. Intracardiac ultrasound might be another useful technique that obviates general anesthesia. This imaging technique has not been reported and could interfere with procedure catheters. If performing the transapical approach, the thoracotomy and ventricular puncture will always require general anesthesia.

Although rarely required, rapid conversion of this minimally invasive technique to an open procedure with sternotomy, full heparinization, and CPB may be required. More commonly, hemorrhage may be sudden and significant, necessitating rapid manipulation of vascular tone and intravascular volume resuscitation. Despite utilization of a less invasive approach, transfusion of blood products was needed in approximately half of our case series. Given the hemodynamic perturbations and serious perioperative risks of transcatheter AV implantation, anesthesiologists will be required for cardiovascular management and emergent resuscitation.

More centers will likely begin addressing aortic valvular disease with transcatheter valve implantations in hybrid operative suites.<sup>32</sup> Anesthesiologists will care for these debilitated patients, applying the expertise necessary to effectively manage severe cardiac and noncardiac disease, within a multidisciplinary team, at an offsite location. The advent of transcatheter AV implantation requires anesthesiologists to apply familiar concepts, methods, and techniques to a novel procedure.

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