Transcatheter Aortic-Valve Implantation for Aortic Stenosis

Policy Number: 7.01.132
Origination: 2/2012
Last Review: 2/2017
Next Review: 2/2018

Policy
Blue Cross and Blue Shield of Kansas City (Blue KC) Transcatheter Aortic Valve Implantation for Aortic Stenosis will provide coverage for transcatheter aortic valve implantation for aortic stenosis when it is determined to be medically necessary because the criteria shown below are met.

When Policy Topic is covered
Transcatheter aortic valve replacement with an FDA-approved transcatheter heart valve system, performed via an approach consistent with the device’s FDA-approved labeling, may be considered medically necessary for patients with aortic stenosis when all of the following conditions are present:
- Severe aortic stenosis (see considerations) with a calcified aortic annulus; AND
- NYHA [New York Heart Association] heart failure Class II, III or IV symptoms; AND
- Left ventricular ejection fraction >20%; AND
- Patient is not an operable candidate for open surgery, as judged by at least two cardiovascular specialists (cardiologist and/or cardiac surgeon); or patient is an operable candidate but is at high risk for open surgery (see Considerations).

Transcatheter aortic valve replacement with a transcatheter heart valve system approved for use for repair of a degenerated bioprosthetic valve may be considered medically necessary when all of the following conditions are present:
- Failed (stenosed, insufficient, or combined) of a surgical bioprosthetic aortic valve; AND
- NYHA heart failure class II, III or IV symptoms; AND
- Left ventricular ejection fraction greater than 20%; AND
- Patient is not an operable candidate for open surgery, as judged by at least 2 cardiovascular specialists (cardiologist and/or cardiac surgeon); or patient is an operable candidate but is at high risk for open surgery (see Considerations section).
When Policy Topic is not covered
Transcatheter aortic valve replacement is considered **investigational** for all other indications.

Considerations
FDA definition of high risk for open surgery:
- Society of Thoracic Surgeons predicted operative risk score of 8% or higher; or
- Judged by a heart team, which includes an experienced cardiac surgeon and a cardiologist, to have an expected mortality risk of 15% or higher for open surgery.

FDA definition of extreme risk or inoperable for open surgery:
- Predicted risk of operative mortality and/or serious irreversible morbidity 50% or higher for open surgery.

For the use of the Sapien or CoreValve device, severe aortic stenosis is defined by the presence of one or more of the following criteria:
- An aortic valve area of less than or equal to 1 cm$^2$
- An aortic valve area index of less than or equal to 0.6 cm$^2$/m$^2$
- A mean aortic valve gradient greater than or equal to 40 mm Hg
- A peak aortic-jet velocity greater than or equal to 4.0 m/s

### Description of Procedure or Service

<table>
<thead>
<tr>
<th>Populations</th>
<th>Interventions</th>
<th>Comparators</th>
<th>Outcomes</th>
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| Individuals:  
- With severe symptomatic aortic stenosis who are at prohibitive risk for open surgery | Interventions of interest are:  
- Transcatheter aortic valve implantation | Comparators of interest are:  
- Medical management | Relevant outcomes include:  
- Overall survival  
- Symptoms  
- Morbid events  
- Treatment-related mortality  
- Treatment-related morbidity |
| Individuals:  
- With severe symptomatic aortic stenosis who are at high risk for open surgery | Interventions of interest are:  
- Transcatheter aortic valve replace implantation | Comparators of interest are:  
- Surgical aortic valve repair | Relevant outcomes include:  
- Overall survival  
- Symptoms  
- Morbid events  
- Treatment-related mortality  
- Treatment-related morbidity |
| Individuals:  
- With severe symptomatic aortic stenosis who are at low or intermediate risk for open surgery | Interventions of interest are:  
- Transcatheter aortic valve implantation | Comparators of interest are:  
- Surgical aortic valve repair | Relevant outcomes include:  
- Overall survival  
- Symptoms  
- Morbid events  
- Treatment-related mortality  
- Treatment-related morbidity |
| Individuals: | Interventions of interest | Comparators of | Relevant outcomes |

Transcatheter aortic valve implantation (TAVI; also known as transcatheter aortic valve replacement) is a potential treatment for patients with severe aortic stenosis. Many patients with aortic stenosis are elderly and/or have multiple medical comorbidities, thus indicating a high, often prohibitive, risk for surgery. This procedure is being evaluated as an alternative to open surgery for high-risk patients with aortic stenosis and as an alternative to nonsurgical therapy for patients with a prohibitive risk for surgery.

For individuals who have severe symptomatic aortic stenosis who are at prohibitive risk for open surgery who receive TAVI, the evidence includes 1 randomized controlled trial (RCT) comparing TAVI with medical management in individuals at prohibitive risk of surgery, and multiple case series. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. For patients who are not surgical candidates due to excessive surgical risk, the PARTNER B trial reported results for patients treated with TAVI by the transfemoral approach compared to continued medical care with or without balloon valvuloplasty. There was a large decrease in mortality for the TAVI patients at 1 year compared with medical care. This trial also reported improvements on other relevant clinical outcomes for the TAVI group. There was an increased risk of stroke and vascular complications in the TAVI group. Despite these concerns, the overall balance of benefits and risks from this trial indicate that health outcomes are improved. For patients who are not surgical candidates, no randomized trials have compared the self-expandable valve with best medical therapy. However, results from the single-arm CoreValve Extreme Risk Pivotal Trial met the authors’ prespecified objective performance goal. The evidence is sufficient to determine qualitatively that the technology results in a meaningful improvement in the net health outcome.

For individuals who have severe symptomatic aortic stenosis who are at high risk for open surgery who receive TAVI, the evidence includes 2 RCTs comparing TAVI with surgical repair in individuals at high risk for surgery, and multiple nonrandomized comparative studies and systematic reviews of these studies. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. For patients who are high risk for open surgery and are surgical candidates, the PARTNER A trial reported noninferiority for survival at 1 year for the balloon-expandable valve compared with open surgery. In this trial, TAVI patients also had higher risks for stroke and vascular complications. Nonrandomized comparative studies of TAVI versus open surgery in high-risk patients have reported no major differences in rates of mortality or stroke between the 2 procedures. Since publication of the PARTNER A trial, the
CoreValve High Risk Trial demonstrated noninferiority for survival at 1 year for the self-expanding prosthesis. This trial reported no significant differences in stroke rates between groups. In an RCT directly comparing the self-expandable with the balloon-expandable valve among surgically high-risk patients, the devices had similar 30-day mortality outcomes, although the self-expandable valve was associated with higher rates of residual aortic regurgitation and requirement for a new permanent pacemaker. Evidence from RCT and nonrandomized studies has suggested that TAVI with a self-expanding device is associated with higher rates for permanent pacemakers postprocedure. However, survival rates appear to be similar between device types, and the evidence does not clearly support the superiority of 1 device over another in all patients. The evidence is sufficient to determine qualitatively that the technology results in a meaningful improvement in the net health outcome.

For individuals who have severe symptomatic aortic stenosis who are at low or intermediate risk for open surgery who receive TAVI, the evidence includes 2 RCTs comparing TAVI with surgical repair in individuals selected without specific surgical risk criteria. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. One investigator-initiated RCT reported no significant difference in the composite rates of death, stroke, or myocardial infarction at 1 year between patients treated with TAVI or with open surgical repair. The rates of adverse events differed between groups, with bleeding, cardiogenic shock, and acute kidney injury higher in patients randomized to open surgery and permanent pacemaker requirement higher in patients randomized to TAVI. A second study was terminated early due to unexpectedly high rates of adverse events in the TAVI arm; it did not report any data on efficacy outcomes. Further RCT evidence in this population is needed to determine the efficacy of TAVI compared to surgery, to better define the early adverse event rate, and to determine whether TAVI is as good as surgery in the longer term. The evidence is insufficient to determine the effects of the technology on health outcomes.

For individuals who have valve dysfunction and aortic stenosis or regurgitation after aortic valve repair who receive transcatheter aortic “valve-in-valve” implantation, the evidence includes case series (largest included 459 patients) and systematic reviews of case series. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. These case series have reported high rates of technical success of valve implantation, and improvement in heart-failure symptoms for most patients. However, they have also reported high rates of short-term complications and high rates of mortality at 1 year postprocedure. There is a lack of evidence comparing valve-in-valve replacement with alternative treatment approaches. The evidence is insufficient to determine the effects of the technology on health outcomes.

Clinical input supported the use of transcatheter aortic “valve-in-valve” replacement for individuals who have degeneration of a surgically implanted aortic valve and who are at high or prohibitive risk for open repair.
Background
Aortic stenosis. Aortic stenosis (AS) is defined as narrowing of the aortic valve opening, resulting in obstruction of blood flow from the left ventricle into the ascending aorta. Progressive calcification of the aortic valve (AoV) is the most common etiology in North America and Europe, while rheumatic fever is the most common etiology in developing countries. (1) Congenital abnormalities of the AoV, most commonly a bicuspid valve, increase the risk for AS, but AS can also occur in a normal aortic valve. Risk factors for calcification of a congenitally normal valve mirror those for atherosclerotic vascular disease, including advanced age, male gender, smoking, hypertension, and hyperlipidemia. (1) Thus, the pathogenesis of calcific AS is thought to be similar to that of atherosclerosis, i.e., deposition of atherogenic lipids and infiltration of inflammatory cells, followed by progressive calcification.

The natural history of AS involves a long asymptomatic period, with slowly progressive narrowing of the valve until the stenosis reaches the severe stage. At this time, symptoms of dyspnea, chest pain, and/or dizziness/syncope often occur and the disorder progresses rapidly. Treatment of AS is primarily surgical, involving replacement of the diseased valve with a bio-prosthetic or mechanical valve by open heart surgery.

Burden of illness.
AS is a relatively common disorder of elderly patients and is the most common acquired valve disorder in the United States. Approximately 2-4% of individuals older than 65 years of age have evidence of significant AS, (1) increasing up to 8% of individuals by age 85 years. (2) In the Helsinki Aging Study, a population-based study of 501 patients aged 75-86 years, the prevalence of severe aortic stenosis by echocardiography was estimated to be 2.9%. (3) In the US, more than 50,000 aortic valve replacements are performed annually due to severe AS.

AS does not cause substantial morbidity or mortality when the disease is mild or moderate in severity. By the time it reaches the severe stage, there is an untreated mortality rate of approximately 50% within 2 years. (4) Open surgical repair is an effective treatment for reversing AS, and artificial valves have demonstrated good durability for periods up to 20 years. (4) However, these benefits are accompanied by a perioperative mortality of approximately 3-4% and substantial morbidity, (4) both of which increase with advancing age.

Unmet needs.
Many patients with severe, symptomatic AS are poor operative candidates. Approximately 30% of patients presenting with severe AS do not undergo open surgery due to factors such as advanced age, advanced left ventricular dysfunction, or multiple medical comorbidities. (5) For patients who are not surgical candidates, medical therapy can partially alleviate the symptoms of AS, but does not affect the underlying disease progression. Percutaneous balloon valvuloplasty can be performed, but this procedure has less than optimal outcomes. (6) Balloon valvuloplasty can improve symptoms and increase flow across the stenotic valve but is associated with high rates of complications such as
stroke, myocardial infarction (MI), and aortic regurgitation. In addition, restenosis can occur rapidly, and there is no improvement in mortality. As a result, there is a large unmet need for less invasive treatments for AS in patients who are at increased risk for open surgery.

Transcatheter aortic valve implantation (TAVI).
TAVI has been developed in response to this unmet need and is intended as an alternative treatment for patients in whom surgery is not an option due to prohibitive surgical risk or for patients who are at high risk for open surgery. The procedure is performed percutaneously, most often through the transfemoral artery approach. It can also be done through the subclavian artery approach and transapically using mediastinoscopy. Balloon valvuloplasty is first performed in order to open up the stenotic area. This is followed by passage of a bioprosthetic artificial valve across the native aortic valve. The valve is initially compressed to allow passage across the native valve and is then expanded and secured to the underlying aortic-valve annulus. The procedure is performed on the beating heart without the need for cardiopulmonary bypass.

There are at least two transcatheter aortic valve devices being tested. The Edwards SAPIEN heart-valve system™ (Edwards Lifesciences, Irvine, CA) is a tri-leaflet bioprosthetic porcine valve that is contained within a stainless steel frame. This device first received FDA approval in 2011, with expanded indications for approval granted in 2012 and 2013.

The CoreValve ReValving System and the second-generation Evolut R system are porcine bioprosthetic valves sewn within a self-expanding nitinol frame, which received FDA approval in 2014. The CoreValve is most commonly inserted via the transfemoral artery approach, but can also be inserted via a non-iliofemoral approach (subclavian artery or direct aortic access). The Evolut R system incorporates a repositionable valve and an in-line catheter design, reducing the diameter of the device delivery system.  

Regulatory Status
In November 2011, the SAPIEN Transcatheter Heart Valve System™ (Edwards LifeSciences, Irvine, CA) was originally approved by the U.S. Food and Drug Administration (FDA) through the premarket approval process for patients with severe aortic stenosis who are not eligible for open-heart procedures and have a calcified aortic annulus. Approval was granted for both the transfemoral and transapical approach. For the transfemoral approach, patient indications were broadened to include patients at high risk for open surgery. For the transapical approach, approval was granted for patients at high risk for open surgery. In September 2012, FDA expanded the indications for the transapical approach to include both inoperable patients and patients at high risk for open surgery. As a result, the SAPIEN Transcatheter Heart Valve System™ is approved for both high-risk and inoperable patients when used by either the transapical or transfemoral approach. In June 2014, the next-generation SAPIEN XT Transcatheter Heart Valve (model 9300TFX) was approved by FDA for use with the NovaFlex+ delivery system. In October 2015, FDA expanded the indication for the SAPIEN valve to
include treatment of a failed surgical bioprosthesis (TAV-in-SAV or “valve-in-valve”).

In January 2014, the CoreValve® Transcatheter Aortic Valve Replacement System (Medtronic, Minneapolis, MN) was approved by FDA through the premarket approval process for patients with symptomatic heart disease due to severe native calcific aortic stenosis and with native aortic annulus diameters between 18 and 29 mm who are judged by a heart team, including a cardiac surgeon, to be at extreme risk or inoperable for open surgical therapy. In June 2014, FDA expanded the indications for the CoreValve® to include patients at high risk for open surgery. FDA labeling indicates that the device can be delivered via femoral, subclavian/axillary, or ascending aortic access. In March 2015, FDA further expanded the indications for the CoreValve® to include treatment of a failed surgical bioprosthesis (TAV-in-SAV or “valve-in-valve”). A second-generation CoreValve® device, the CoreValve Evolut™ R System, received FDA approval in June 2015.

Other transcatheter aortic valve systems are under development. For example, the Lotus™ Aortic Valve Replacement System (Boston Scientific, Marlborough, MA) is another repositionable valve that incorporates an outer seal to reduce paravalvular regurgitation. It has been evaluated in single-arm studies. The JenaValve™ (JenaValve Technology, Munich) is a repositionable valve designed for transapical placement that has been evaluated in single-arm studies.

### Rationale
This evidence review was created in December 2011 and has been updated periodically with literature reviews of the MEDLINE database. The most recent literature review covered the period through December 9, 2015.

The evidence on transcatheter aortic valve implantation (TAVI) consists of many uncontrolled case series, 2 pivotal randomized controlled trials (RCTs; the PARTNER trial and the CoreValve High Risk Study), and an RCT directly comparing the CoreValve and the SAPIEN devices. These studies have reported on 2 potential populations for TAVI: (1) patients who are not surgical candidates and (2) patients who are high risk for surgery but still considered to be surgical candidates. Evidence for these 2 groups of patients will be discussed separately.

### Outcomes for TAVI in Patients Who Are at Prohibitive Risk for Open Surgery

#### Systematic Reviews
Systematic reviews on whether TAVI improves outcomes for patients who are not suitable candidates for open surgery consist of summaries of case series. An Agency for Healthcare Research and Quality (AHRQ)–sponsored systematic review in 2010 reviewed 84 publications (total N=2375 patients). Implantation was successful in 94% of patients overall, with higher success rates reported in more recent publications. The aggregate 30-day survival was 89% across all studies.
Adverse event (AE) rates were reported in the larger case series, with an estimated 30-day rate of major cardiovascular AEs and stroke of 8%.

A second systematic review was published in 2011 by Figulla et al.\textsuperscript{16} It included studies that enrolled symptomatic patients with severe aortic stenosis who had a mean age of 75 years or older, reported on 10 or more patients, and had a follow-up duration of 12 months or more. Twelve studies met these criteria and were compared with a group of 11 studies that treated severe aortic stenosis with nonsurgical therapy. The procedural success in these studies ranged from 86% to 100%, and the 30-day mortality ranged from 5.3% to 23%. The combined mean survival rate at 1 year was 75.9% (confidence interval [CI], 73.3% to 78.4%). This 1-year survival rate compared favorably with medical therapy, which was estimated to be 62.4% (95% CI, 59.3% to 65.5%).

**Randomized Controlled Trials**

The PARTNER trial was a pivotal multicenter RCT of TAVI performed in the United States, Canada, and Germany, using the SAPIEN system. Leon et al reported results of patients from this trial with severe aortic stenosis who were not candidates for open surgery, referred to as the PARTNER B trial.\textsuperscript{17} To be classified as unsuitable for open surgery, patients had to have a predicted probability of 50% or higher for death or a serious irreversible condition at 30 days postsurgery. This probability was determined by 2 surgeon investigators using clinical judgment and the Society of Thoracic Surgery (STS) risk score. The executive committee of the PARTNER trial reviewed all patient selection decisions and approved the classification of patients as unsuitable for surgery. A total of 3105 patients were screened for aortic valve surgery, and 12% of them were included in the cohort of patients deemed unsuitable for surgery.

A total of 358 patients were randomized to TAVI or usual care. TAVI was performed by the transfemoral approach under general anesthesia. Standard therapy was determined by the treating clinicians. In most cases (83.8%), standard treatment included balloon valvuloplasty of the aortic valve. A small number of patients (6.7%) underwent open surgical valve replacement, despite the high risk, and another 2.2% of patients underwent TAVI at a center outside the United States not participating in the trial. The primary outcome was death from any cause during the trial (median follow-up, 1.6 years). A coprimary end point was the composite of time to death from any cause or time to repeat hospitalization related to aortic stenosis or TAVI. Secondary end points were cardiovascular mortality, New York Heart Association (NYHA) functional class, the rates of hospitalizations due to aortic stenosis or TAVI, the 6-minute walk test (6MWT), valve performance as measured by echocardiography, and procedural complications (myocardial infarction [MI], stroke, acute kidney injury [AKI], vascular complications, bleeding).

Mean age of enrolled patients was 83.2 years. Some baseline imbalances in the patient population indicated that the standard therapy group may have had a higher severity of illness. Standardized scores of surgical risk were higher in the standard therapy group. The logistic EuroSCORE was significantly higher in the
standard therapy group (30.4±19.1) than in the TAVI group (26.4±17.2; p=0.04) and the STS score was numerically higher but was not statistically significant (12.1±6.1 vs 11.2±5.8, respectively; p=0.14). Significantly more patients in the standard therapy group had chronic obstructive pulmonary disease (52.5% vs 41.3%, p=0.04) and atrial fibrillation (48.8% vs 32.9%, p=0.04), and there was a nonsignificant trend for more patients in the standard therapy group having a lower ejection fraction (51.1% vs 53.9%) and frailty, as determined by prespecified criteria (28.0% vs 18.1%), all respectively.

Death from any cause at 1 year after enrollment was lower for the TAVI group (30.7% vs 49.7%, p<0.001). This represents a 19% absolute risk reduction, a 38.2% relative risk (RR) reduction, and a number needed to treat of 5.3 to prevent 1 death over a 1-year follow-up. Most secondary outcomes also favored the TAVI group. Cardiovascular death was lower in the TAVI group (19.6% vs 44.1%, p<0.001). The composite of all-cause mortality and repeat hospitalizations was reached by 42.5% of the patients in the TAVI group compared with 70.4% in the standard therapy group. Symptoms and functional status were also superior in the TAVI group. The percentage of patients in NYHA class I or II at 1 year was higher for the TAVI group (74.8% vs 42.0%, p<0.001), and there was a significant improvement in the 6MWT for the TAVI group but not for the standard therapy group (between-group comparisons not reported). Subgroup analysis did not report any significant differences in outcomes according to clinical and demographic factors.

Complication rates were higher for the TAVI group. Stroke or transient ischemic attack (TIA) at 1 year was more than twice as frequent for the TAVI group (10.6% vs 4.5%, p=0.04). Major bleeding and vascular complications occurred in a substantial percentage of patients undergoing TAVI (22.3% vs 11.2%, p=0.007) and were significantly higher than in the standard therapy group (32.4% vs 7.3%, p<0.001).

Quality of life (QOL) outcomes from this trial were reported by Reynolds et al in 2011. QOL outcomes were evaluated using the Kansas City Cardiomyopathy Questionnaire (KCCQ) summary score, the 12-Item Short-Form Health Survey (SF-12), and the EuroQoL (EQ-5D). The number of participants who completed the QOL measures was not clearly reported; estimates from graphical representation show that between 149 and 170 patients in the TAVI group and 138 and 157 patients in the medical therapy group completed baseline QOL measures. At follow-up time points of 30 days, 6 months, and 12 months, change in the QOL scores was greater for the TAVI group. At 30 days, the mean difference in the KCCQ score was 13.3 points (95% CI, 7.6 to 19.0; p<0.001). This mean difference increased at later time points to 20.8 points (95% CI, 14.7 to 27.0; p<0.001) at 6 months and 26.0 points (95% CI, 18.7 to 33.3; p<0.001) at 12 months. Changes in the SF-12 and EQ-5D measures showed similar patterns.

Two-year outcomes were reported from the PARTNER trial in 2012. Mortality at 2 years was 43.3% in the TAVI group compared with 68.0% in the medical therapy group (hazard ratio [HR], 0.58; 95% CI, 0.36 to 0.92; p=0.02). Cardiovascular
mortality was also lower with TAVI (31.0%) than with medical therapy (62.4%; p<0.001). Rate of hospitalization over the 2-year period was lower with TAVI (35.0%) than with medical therapy (72.5%; p<0.001).

In 2014, Svensson et al reported detailed mortality outcomes for both arms of the PARTNER trial: the PARTNER B RCT (previously described), which compared surgical repair with TAVI in prohibitive surgical risk patients, and the PARTNER A RCT, which compared surgical repair with TAVI in high surgical risk patients, described next. For the 358 patients considered inoperable and enrolled in the PARTNER B RCT, at last follow-up, 237 patients had died. Those randomized to standard therapy exhibited an early peak in mortality that was higher than those randomized to TAVI and that persisted beyond 6 months. Compared with standard therapy, the estimated net lifetime benefit added by transfemoral TAVI was 0.50 years (90% CI, 0.30 to 0.67).

In 2014, Kapadia et al reported on 3-year outcomes for prohibitive-risk patients (N=358) randomized to standard therapy or TAVI in the PARTNER trial, along with all outcomes (early and long term) for randomly assigned inoperable PARTNER patients, including 91 subjects in the randomized PARTNER continued access study. Analysis of the pooled randomly assigned patients was anticipated in the study protocol. At the 3-year follow-up for the pivotal trial subjects, all-cause mortality was 54.1% in the TAVI group and 80.9% in the standard therapy group (HR=0.53; 95% CI, 0.41 to 0.68; p<0.001). Incidence of stroke was higher in the TAVI group (15.7%) than in the standard therapy group at 3 years (5.5%; HR=3.81; 95% CI, 1.26 to 6.26; p=0.012). However, at 3 years, the incidence of the composite of death or stroke was significantly lower in the TAVI group (57.4% vs 80.9%; HR=0.60; 95% CI, 0.46 to 0.77; p<0.001). Survivors at 3 years who had undergone TAVI were more likely to have NYHA class I or II symptoms than those who had received standard therapy. In the pooled sample, at the 2- and 3-year follow-ups, mortality was lower for patients who had undergone TAVI than in those who had standard therapy (2 years: 44.8% vs 64.3%; 3 years: 54.9% vs 78.0%; all p<0.001).

**Case Series and Cohort Studies**

Many case series of TAVI have been published in the last 10 years, most of which have included those not candidates for open surgery. However, the selection process for TAVI has largely been subjective, with the expert opinion of the surgeons and/or cardiologists as the main factor determining suitability for open surgery. As a result, there may be some overlap in these series with patients who are surgical candidates, but the distinction cannot be easily gleaned from the reported studies.

Some of the larger and/or prospective case series are discussed next. Included are the series that have reported on the pivotal trials leading to devices approvals (ie, Popma et al [2014] and Reardon et al [2014]) or on postapproval registries (ie, Mack et al [2013]). In addition, series that discuss the longer term durability of the TAVI devices are included.
**CoreValve Extreme Risk Pivotal Trial**

In 2014, Popma et al published results of the CoreValve Extreme Risk Pivotal Trial, which was designed to evaluate the CoreValve self-expanding valve among patients with severe aortic stenosis who were considered to be at extreme risk for surgical aortic valve replacement (AVR). The trial included patients with severe aortic stenosis and NYHA class II or greater symptoms who were considered to be at extreme risk if 2 cardiac surgeons and 1 interventional cardiologist at the clinical site estimated a 50% or greater risk for mortality or irreversible morbidity at 30 days with surgical repair. The study’s primary end point was the 12-month rate of all-cause mortality or major stroke in the “attempted implant” population. This population included all patients who underwent a documented valve implant via an iliofemoral approach. The study defined an objective performance goal of 43% for all-cause mortality or major stroke at 12 months postprocedure. This goal was based on 2 sources: (1) a weighted meta-analysis of 7 balloon aortic valvuloplasty studies, which yielded a rate of 12-month all-cause mortality or major stroke of 42.7% (95% CI, 34.0% to 51.4%); and (2) an adjusted estimate based on the lower 95% confidence bound of 43% in the standard therapy arm of inoperable patients in the PARTNER trial.

Four hundred eighty-nine patients were included in the attempted implant analysis population of 506 patients recruited (11 of whom exited the study prior to treatment, 6 of whom did not complete the procedure with iliofemoral access). The Kaplan-Meier rate of the primary end point (all-cause mortality or major stroke) was 26.0% (upper bound of 95% CI, 29.9%), which was lower than the prespecified performance goal of 43% (p<0.001). The rate of all-cause mortality at 1 year following enrollment was 24.3%, while the rate of major stroke at 12 months was 4.3%. These rates are comparable or better than those seen in the TAVI arm of the PARTNER pivotal trial, although patients in the PARTNER pivotal trial had a higher baseline STS score (12.1% in the PARTNER trial vs 10.3% in the CoreValve Extreme Risk trial).

Two-year results from the CoreValve Extreme Risk Pivotal Trial were reported by Yakubov et al in 2015. The Kaplan-Meier rate of all-cause mortality or major stroke was 38.0% (upper bound of 95% CI, 42.6%). The incremental rates between years 1 and 2 were 12.3% for all-cause mortality, 7.9% for cardiovascular mortality, and 0.8% for stroke.

In 2015, Osnabrugge et al reported on health status outcomes for the 471 patients who underwent TAVI via the transfemoral approach. On average, general and disease-specific QOL scores both showed substantial improvements after TAVI. However, 39% of patients had a poor outcome at 6 months (22% death, 16% very poor QOL, 1.4% QOL declined).

In 2014, Reardon et al reported outcomes for the group of patients enrolled in the CoreValve Extreme Risk Pivotal Trial who received the device through an approach other than the iliofemoral. Inclusion criteria and procedures were the same as for the primary CoreValve Extreme Risk Trial. One hundred fifty patients with
prohibitive iliofemoral anatomy were included and received the CoreValve device through an open surgical approach via the subclavian artery (n=70) or a direct aortic approach via a median hemisternotomy or right thoracotomy (n=80). Included patients were elderly (mean age, 81.3 years) and significantly symptomatic, with 92% of subjects having NYHA class III or IV heart disease. At 30 days postprocedure, 23 (15.3%) patients had met the primary end point of all-cause mortality or major stroke; of the 23 patients, 17 (11.3%) had died and 11 (7.5%) had experienced a major stroke. At 12 months postprocedure, 59 (39.4%) patients had met the primary end point; of those, 54 (36%) had died and 13 (9.1%) had experienced a major stroke. The 30-day mortality of 11.3% was higher than that reported in the studies of TAVI that used a transfemoral or an iliofemoral approach (PARTNER B RCT and the CoreValve Extreme Risk Pivotal Trial), but similar to the 30-day mortality reported by the patients treated with a transapical approach (PARTNER A trial).

Postapproval Registries
In 2013, Mack et al reported outcomes after TAVI from 224 hospitals participating in the Edwards SAPIEN device post Food and Drug Administration (FDA) approval registry. From November 2011 to May 2013, the registry included at total of 7710 patients who underwent TAVI placement, of whom 1559 (20%) patients were considered inoperable and 6151 (80%) were considered high risk but operable. Of those considered inoperable, 1139 underwent device placement via transfemoral access, while 420 underwent device placement via nontransfemoral access. In-hospital mortality was 5.4% and 7.1% for the inoperable patients who underwent TAVI via transfemoral and nontransfemoral access, respectively. Thirty-day clinical outcomes were reported for 694 inoperable patients; of those, 30-day mortality was 6.7% and 12.6% for patients who underwent TAVI via transfemoral and nontransfemoral access, respectively.

Additional Case Series
The prospective nonrandomized ADVANCE study had central adjudication of end points and adverse events to evaluate the CoreValve implants in individuals with severe symptomatic aortic stenosis who were considered inoperable or at higher risk for surgical AVR. The study enrolled 1015 patients, of whom 996 were implanted, most (88.4%) by the iliofemoral approach, with 9.5% and 2.1% by the subclavian and direct aortic approaches, respectively. For the study’s primary end point of major adverse cardiac and cerebrovascular events (MACCE; a composite of all-cause mortality, MI, stroke, or reintervention), rates were 8.0% (95% CI, 6.3% to 9.7%) at 30 days and 21.2% (95% CI, 18.4% to 24.1%) at 12 months. The all-cause mortality rate was 4.5% (95% CI, 3.2% to 5.8%) at 30 days and 17.9% (95% CI, 15.2% to 20.5%) at 12 months. Overall, strokes occurred in 3.0% (95% CI, 2.0% to 4.1%) at 30 days and in 4.5% (95% CI, 2.9% to 6.1%) at 12 months. A new permanent pacemaker was implanted in 26.3% (95% CI, 23.5% to 29.1%) and in 29.2% (95% CI, 25.6% to 32.7%) at 30 days and 12 months of follow-up, respectively. Patients were grouped into 3 categories of surgical risk based on logistic EuroSCORE values (≤10%, >10% but ≤20%, and >20%). Thirty-day survival did not differ significantly across risk groups, but 12-
month rates of MACCE, all-cause mortality, cardiovascular mortality, and death from any cause or major stroke were higher for higher surgical risk patients.

The 2 largest series included in the AHRQ review (described previously) reported on 646 patients treated with the CoreValve and 339 patients treated with the SAPIEN valve. The CoreValve study by Piazza et al was notable in that it used more objective patient selection criteria than is common in this literature. Their criteria for eligibility included: (1) logistic EuroSCORE of 15% or higher, (2) age of 75 or older, or (3) age of 65 or older with liver cirrhosis, pulmonary insufficiency, pulmonary hypertension, previous cardiac surgery, porcelain aorta, recurrent pulmonary emboli, right ventricular insufficiency, previous chest burns or radiation precluding open surgery, or body mass index of 18 kg/m^2 or less. Procedural success was 97% and 30-day survival was 92%. The 30-day combined rate of death, MI, or stroke was 9.3%. The study by Rodes-Cabau et al (conducted in Canada) used SAPIEN valve. This study had subjective inclusion criteria, relying on the judgment of the participating surgeons to determine eligibility for TAVI. The procedural success rate was 93.3%, and the 30-day mortality was 10.4%. The authors also reported a mortality rate of 22.1% at a median follow-up of 8 months.

Additional series have described experiences with TAVI in European centers. In the largest series identified, with up to 6 years of follow-up, Ludman et al reported on 3980 TAVI procedures in the United Kingdom, using data from a national registry linked to National Health Service outcomes. One-, 2-, 5-, and 6-year survival rates were 81.7%, 72.8%, 46.9%, and 37.3%, respectively. Zahn et al, in a large case series from Germany, reported on 697 patients treated with the CoreValve system. Procedural success was 98.4%, and 30-day mortality was 12.4%. Another large case series from Italy included 663 patients treated with the CoreValve device. Procedural success was 98%, and mortality at 1 year was 15%.

**Section Summary: Outcomes for TAVI in Patients Who Are at Prohibitive Risk for Open Surgery**

Numerous case series have demonstrated the feasibility and short-term efficacy for TAVI in patients who are not surgical candidates. In the PARTNER B trial, there was a large decrease in all-cause mortality and cardiovascular mortality at 1 year for TAVI compared with standard therapy. Subsequent publications from this same trial reported that the mortality benefit was maintained at 2 years and that QOL was improved for the TAVI group. Baseline group differences were present, indicating that the TAVI group may have been healthier. While these differences are unlikely to account for the degree of mortality benefit reported, they may have resulted in overestimation of the mortality benefit.

The benefit in mortality was accompanied by an increased stroke risk as well as substantial increases in vascular complications and major bleeding. There is also uncertainty concerning the generalizability of these results, because patient selection was primarily determined by the cardiovascular surgeons and/or
cardiologists. It is not known whether this type of decision making is reliable across the range of practicing clinicians.

**Outcomes for TAVI in Patients Who Are at High Risk for Open Surgery**

**Systematic Reviews**

Several systematic reviews have addressed whether TAVI improves outcomes for patients at high, but not prohibitive, risk for aortic stenosis as an alternative to open surgery.

The evidence in most of these systematic reviews is derived largely from nonrandomized comparative studies, because only 1 RCT had been published at the time of the reviews (the PARTNER trial). Panchal et al reported results from a meta-analysis of 17 studies that included 4659 patients, 2267 treated with TAVI, and 2392 treated with open surgery. Patients in the TAVI group were more severely ill, as evidenced by a EuroSCORE for predicted 30-day mortality, which was higher by a mean of 3.7 points compared with patients undergoing open surgery. On combined analysis, there were no differences between groups for 30-day mortality, mortality at longest follow-up, cardiovascular mortality, MI, stroke, or TIA. Patients in the open surgery group had a higher incidence of major bleeding complications (RR=1.42; 95% CI, 1.20 to 1.67; p<0.001). In a similar meta-analysis that included 17 studies reporting on 4873 patients, there were no differences between TAVI and open surgery in early mortality (odds ratio [OR], 0.92; 95% CI, 0.70 to 1.2) or mid-term mortality, defined as between 3 months and 3 years (HR=0.99; 95% CI, 0.83 to 1.2).

**Randomized Controlled Trials**

**PARTNER A Trial**

Results from the cohort of patients in the PARTNER trial of the SAPIEN valve who were at high risk for open surgery, but still suitable candidates, were published in June 2011. The inclusion and exclusion criteria were generally the same as those for the prior cohort, except that these patients were classified as high risk for surgery rather than unsuitable for surgery. For high risk, patients had to have a predicted perioperative mortality of 15% or higher, as determined by a cardiac surgeon and cardiologist using clinical judgment. An STS score of 10 or higher was included as a guide for high risk, but an STS score threshold was not a required criterion for enrollment. The executive committee of the PARTNER trial reviewed all patient selection decisions and approved the classification of patients as high risk for surgery. A total of 3105 patients were screened for aortic valve surgery, and 22.5% of them were eventually included in the cohort of patients deemed high risk for surgery.

A total of 699 patients were randomized to TAVI or surgical aortic valve repair. The primary hypothesis was that TAVI was noninferior to open AVR, using a 1-sided noninferiority boundary of 7.5% absolute difference in mortality at 1 year. Patients were first evaluated to determine if they were eligible for TAVI via the transfemoral approach. Four hundred ninety-two patients were eligible for
transfemoral TAVI; the remaining 207 were categorized as the transapical placement cohort. Within each cohort (transfemoral and transapical), patients were randomized to either surgical aortic valve repair (n=351) or TAVI (n=348).

The primary outcome was death from any cause at 1-year follow-up. A second powered end point was noninferiority at 1 year for patients undergoing TAVI by the transfemoral approach. Secondary end points were cardiovascular mortality, NYHA functional class, rehospitalizations, the 6MWT, valve performance as measured by echocardiography, and procedural complications (MI, stroke, AKI, vascular complications, bleeding). The mean age of enrolled patients was 83.6 years in the TAVI group and 84.5 years in the open AVR group. Other baseline demographics and clinical characteristics were generally well-balanced, except for a trend toward an increased percentage of patients in the TAVI group with a creatinine level greater than 2.0 (11.1% vs 7.0%, p=0.06).

Death from any cause at 1 year following enrollment was 24.2% for the TAVI group and 26.8% for the open AVR group (p difference between groups, p=0.44). The upper limit of the 95% CI for the between-group difference was a 3.0% excess mortality in the TAVI group, which was well within the noninferiority boundary of 7.5%. Thus the criterion of noninferiority was met (p=0.001). For the subgroup of patients who underwent TAVI by the transfemoral approach, results were similar with 22.2% mortality in the TAVI group compared with 26.4% mortality in the open AVR group (p=0.002 for noninferiority). The secondary outcomes of cardiovascular mortality (14.3% vs 13.0%, p=0.63) and rehospitalizations (18.2% vs 15.5%, p=0.38) did not differ significantly between the TAVI and the open AVR groups. The percentage of patients in NYHA class I or II at 1 year was similar between groups at 1 year, as was improvement on the 6MWT. On subgroup analysis, there was a significant effect for gender, with women deriving greater benefit than men (p=0.045), and a significant effect for prior coronary artery bypass graft (CABG), with patients who had not had prior CABG deriving greater benefit in the TAVI group.

Certain complication rates showed significant differences between groups. Stroke or TIA at 1 year was higher for the TAVI group (8.3% vs 4.3%, respectively, p=0.04). Vascular complications occurred in 18.0% of patients undergoing TAVI compared with 4.8% in the open AVR group (p=0.01), and major vascular complications were also higher in the TAVI group (11.3% vs 3.5%, p=0.01). On the other hand, major bleeding was more common in the open group (25.7%) compared with the TAVI group (14.7%; p=0.01).

Five-year results from the PARTNER trial were reported by Mack et al (2015). At 5-year follow-up, in the intention-to-treat population, the risk of death from any cause did not differ significantly between patients treated with TAVI (67.8%) and those treated with surgical repair (62.4%; HR=1.04; 95% CI, 0.86 to 1.24; p=0.76). As reported in the original PARTNER trial findings, moderate or severe aortic regurgitation—primarily paravalvular regurgitation—was more common among TAVI-treated patients. Among TAVI-treated patients, the presence of aortic regurgitation was associated with increased 5-year mortality risk (72.4% for
moderate or severe aortic regurgitation vs 56.6% for mild aortic regurgitation or less; p=0.003).

Reynolds et al published QOL results from the PARTNER A trial in 2012. QOL outcomes were evaluated using the KCCQ summary score, the SF-12, and the EQ-5D. Of 699 patients in the trial, 628 completed baseline QOL measures. Patients in both the TAVI group and the surgical AVR group demonstrated significant improvements in all QOL measures over the 12 months following treatment. The TAVI group had superior improvement at 1 month on the KCCQ (mean difference, 9.9; 95% CI, 4.9 to 14.9; p<0.001), but this difference was no longer present at 6 or 12 months. A similar pattern of results was reported for the SF-12 and EQ-5D measures.

Genereux et al published a follow-up study from the PARTNER A trial reporting on bleeding complications. Using an as-treated approach, this analysis included 313 patients treated with surgical repair, 240 patients treated with transfemoral TAVI, and 104 patients treated with transapical TAVI. Seventy-one (22.7%) patients treated with surgery had major bleeding complications within 30 days of the procedure, compared with 27 (11.3%) of those treated with transfemoral TAVI and 9 (8.8%) of those treated with transapical TAVI (p<0.001).

**U.S. CoreValve High Risk Study**

In 2014, Adams et al published results of the U.S. CoreValve High Risk Study. This RCT compared surgical AVR with TAVI using the CoreValve device in patients who had severe aortic stenosis and were considered at increased risk of death during surgery. The study randomized 795 patients in a 1:1 ratio to TAVI or open AVR. Patients were considered to be at “increased surgical risk” if 2 cardiac surgeons and 1 interventional cardiologist estimated that the risk of death within 30 days of surgery was 15% or more and that the risk of death or irreversible complications within 30 days after surgery was less than 50%. The primary analysis was based on the as-treated population, which included all patients who underwent an attempted implantation. For the study’s primary outcome, the rate of death from any cause at 1 year was lower in the TAVI group (14.2%) than in the surgical group (19.1%; absolute risk reduction, 4.9%; upper boundary of 95% CI, -0.4%, which was less than the predefined noninferiority margin of 7.5%-point difference between the groups; noninferiority, p<0.001, superiority p=0.04). Major vascular complications and permanent pacemaker implantations were significantly more frequent in the TAVI group than in the surgical group: at 30 days, major vascular complications occurred in 5.9% of the TAVI group compared with 1.7% of the surgical group (p=0.003), while permanent pacemaker implantation was required in 19.8% of the TAVI group compared with 7.1% of the surgical group (p<0.001). In contrast to the PARTNER trial, the TAVI group did not have a higher rate of any stroke at 1 year postprocedure than the surgical group (8.8% for TAVI vs 12.6% for surgery; p=0.10).

Two-year follow-up results from the U.S. CoreValve High Risk study were published in 2015 by Reardon et al. At that point, the mortality benefits seen with TAVI were maintained.
Nonrandomized Comparative Studies
Since publication of the pivotal RCTs and systematic reviews described previously, a number of nonrandomized studies have compared surgical and transcatheter aortic valve repair.\(^41-43\) Given the availability of RCT evidence, these studies provide limited additional information on the efficacy of TAVI.

Section Summary: Outcomes for TAVI in Patients Who Are at High Risk for Open Surgery
The most direct evidence related to the use of TAVI for aortic stenosis in patients who are at high but not prohibitive risk of surgery comes from 2 industry-sponsored RCTs. The PARTNER RCT in high-risk patients who were eligible for surgical AVR reported no differences between TAVI and open AVR in terms of mortality at 1 year and most major secondary outcomes. The noninferiority boundaries for this trial included an upper limit of 7.5% absolute increase in mortality, but, in actuality, the reported mortality for the TAVI group was lower than that for the open group, although not significantly better. QOL was also similar at 1 year between the TAVI and AVR groups. Stroke or TIA was significantly more common for the TAVI group, occurring at a rate of almost 2 times that reported for open surgery. Other secondary outcomes were similar between groups, except for higher rates of vascular complications in the TAVI group and higher rates of major bleeding in the open surgery group. As in the first PARTNER cohort, there is concern for generalizability of results because the patient selection process relied largely on the judgment of surgeons and cardiologists participating in the trial. The U.S. CoreValve High Risk Study reported that TAVI was noninferior to open surgical repair. Although, in contrast to the PARTNER A RCT, stroke rates were not higher in patients who underwent TAVI, a requirement for permanent pacemaker was more common in the TAVI group.

Outcomes for TAVI in Patients Who Are at Low or Intermediate Risk for Open Surgery
Most research on TAVI has focused on its use as an alternative to open surgery in patients with at least a high risk of surgery. Two RCTs were identified that evaluated the use of TAVI in patients who were not at high risk of open surgery. In 2015, Thyregod et al reported results of the NOTION trial, which compared TAVI to surgical repair in 280 patients with severe aortic stenosis who were 70 years old or older, regardless of predicted risk of death after surgery.\(^{44}\) Patients randomized to TAVI underwent implantation of the CoreValve self-expanding prosthesis by the femoral (preferred) or subclavian route. The study was powered to detect an absolute risk reduction of 10% or a relative risk reduction of 66.7% in primary outcome at 1 year. At baseline, 81.8% of the study population was considered to be at low risk (STS score <4). In intention-to-treat analysis, rates of the primary outcome (the composite rate of death from any cause, stroke, or MI at 1 year) did not differ significantly between groups (13.1% for TAVI vs 16.3% for surgical repair; absolute difference, -3.2%; \(p=0.43\) for superiority). TAVI-treated patients had lower rates of major or life-threatening bleeding (11.3% vs 20.9%, \(p=0.03\)), cardiogenic shock (4.2% vs 10.4%, \(p=0.05\)), stage II or III AKI
(0.7% vs 6.7%, p=0.01), and new onset or worsening atrial fibrillation (16.9% vs 57.8%, p<0.001), all respectively. However, TAVI-treated patients were more likely to have conduction abnormalities requiring a permanent pacemaker (34.1% vs 1.6%, p<0.001). Both groups showed improvements in NYHA functional class. However, more TAVI-treated patients were in NYHA functional class II at 1-year follow-up (29.5% vs 15.0%, p=0.01).

A previous RCT, the STACCATO trial, was designed to compare transapical TAVI with the SAPIEN valve with surgical aortic valve repair in operable patients with isolated aortic stenosis, without selection based on predicted risk of death after surgery. However, the study was prematurely terminated due to an increase in adverse events in the TAVI arm. The available results were reported by Nielsen et al in 2012. The trial was limited by a design that assumed a low event rate (2.5%). In addition, operators’ experience with the device and implantation techniques at the time of the study may not be representative of current practice.

**Section Summary: Outcomes for TAVI in Patients Who Are at Low or Intermediate Risk for Open Surgery**

One investigator-initiated RCT reported no significant difference in the composite rate of death, stroke, or MI at 1 year between patients treated with TAVI and those treated with open surgical repair. The rates of adverse events differed between groups, with bleeding, cardiogenic shock, and AKI higher in patients randomized to open surgery and permanent pacemaker requirement higher in patients randomized to TAVI. A second study was terminated early due to unexpectedly high rates of adverse events in the TAVI arm; it did not report any data on efficacy outcomes. Furthermore, RCT evidence in this population is needed to determine the efficacy of TAVI compared to surgery.

**Comparisons of Different TAVI Devices**

As of 2014, there were 2 FDA-approved TAVI devices, one of which relies on a self-expanding mechanism and one which relies on a balloon-expanding mechanism. A relatively small body of evidence has addressed whether different TAVI devices are associated with different outcomes.

**Systematic Reviews**

In 2014, Athappan et al published results from a systematic review and meta-analysis that evaluated the risk of stroke for patients undergoing TAVI, comparing the transfemoral with transapical access approaches and the self-expanding (CoreValve) valve design with the balloon-expandable (SAPIEN) valve design. The reviewers identified 25 multicenter studies and 33 single-center studies that met their selection criteria, including 3 randomized comparisons, all from the PARTNER study. At 30 days postprocedure, there were no differences in stroke rates. In multicenter studies, the incidence of stroke 30 days postprocedure was 2.4% (95% CI, 1.9% to 3.2%) for centers using the self-expanding valve and 3.0% (95% CI, 2.4% to 3.7%) for centers using the balloon-expanding valve. In pooled analysis, there was no difference in the in-hospital/30-day stroke rate between the self-expanding and balloon-expanding valve groups (pooled
OR=1.03; 95% CI, 0.78 to 1.35). Findings were similar for single-center studies. Stroke rates improved with increasing center experience with TAVI.

**Randomized Controlled Trials**

In 2014, Abdel-Wahab et al published results of an RCT (the CHOICE trial) that directly compared the CoreValve self-expandable valve with the SAPIEN balloon-expandable valve among patients at high risk for surgery with severe aortic stenosis.47 Two hundred forty-one patients were randomized, 121 to the balloon-expandable valve group and 120 to the self-expandable valve group. The study’s primary end point was device success, a technical composite end point including (1) successful vascular access, delivery, and deployment of the device and successful retrieval of the delivery system; (2) correct positioning of the device in the proper anatomic location; (3) intended performance of the prosthetic heart valve; and (4) only 1 valve implanted in the proper anatomic location. Device success occurred in 116 (95.9%) of 121 of patients in the balloon-expandable group compared with 93 (77.7%) of 120 patients in the self-expandable valve group (RR=1.24; 95% CI, 1.12 to 1.37). This difference was driven largely by differences in rates of residual aortic regurgitation, which occurred in 4.1% of the balloon-expandable valve group and 18.3% of the self-expandable valve group (RR=0.23; 95% CI, 0.09 to 0.58; p<0.001). Cardiovascular mortality at 30 days and bleeding and vascular complications did not differ significantly between the groups. Patients in the balloon-expandable group less frequently required placement of a new pacemaker (17.3% vs 37.6%, p=0.001).

One-year follow-up results from the CHOICE trial were published in 2015.48 Clinical follow-up at 1 year was available for 100% of patients in the balloon-expandable valve group and 97% of those in the self-expandable valve group. From 30 days to 1 year, there were 16 and 9 additional deaths in the balloon-expandable and self-expandable valve groups, respectively. At 1 year, there was no significant difference in all-cause mortality between the balloon expandable (17.4%) and self-expandable (12.8%) groups (RR=1.35; 95% CI, 0.73 to 2.5; p=0.037). Similarly, there were no significant between-group differences in cardiovascular mortality or stroke frequency. The cumulative rate of new pacemaker implantation at 1 year postprocedure, however, was higher in the self-expandable valve group (38.0%) than the balloon-expandable group (23.4%; p=0.02). The evolution of aortic regurgitation did not differ between groups over time, although paravalvular aortic regurgitation and total aortic regurgitation remained less common in the self-expandable valve group (paravalvular aortic regurgitation: 1.1% vs 12.1%; p=0.005; total aortic regurgitation: 1.1% vs 13.1%; p=0.02).

**Nonrandomized Comparative Studies**

In 2014, Van Belle et al compared rates of postprocedural aortic regurgitation for TAVI with balloon-expandable or self-expandable valves, using data from a large, national French registry of patients undergoing TAVI from January 2010 to October 2011.49 Significant postprocedural aortic regurgitation (>grade 1) has been associated with worse long-term outcomes. For this analysis, the authors included 1872 (67.6%) patients who received a balloon-expandable valve and 897 (32.4%) who received a self-expandable valve. Postprocedural aortic regurgitation greater
than grade 1 occurred in 15.8% of all patients, and in 21.5% of patients who received a self-expandable valve (vs 13.0% of those who received a balloon-expandable valve; p<0.001); this difference remained significant after controlling for potential confounding factors.

Dworakowski et al used data from a registry of TAVI procedures in the United Kingdom, the U.K. TAVI Registry, to compare differences between balloon-expandable and self-expandable valves in terms of paraprosthetic aortic regurgitation post-TAVI. The analysis included 2440 patients enrolled at 25 U.K. centers, 52.7% and 47.2% of whom received a balloon-expandable or a self-expandable device, respectively. Ten percent of patients had moderate or severe post-TAVI paraprosthetic aortic regurgitation. The use of a self-expanding valve was associated with paraprosthetic aortic regurgitation, with 13.6% of those with a self-expanding valve experiencing moderate or severe aortic regurgitation (vs 7.6% of those with balloon-expandable valve; p<0.001). However, overall mortality did not differ between valves. In regression modeling, moderate-to-severe aortic regurgitation was a significant predictor of mortality in patients treated with a balloon-expandable valve (HR=1.97; 95% CI, 1.47 to 2.61), but not in patients treated with a self-expanding valve (HR=1.13; 95% CI, 0.83 to 1.51). The authors noted that the basis for this difference in aortic regurgitation–related mortality risk is not well understood.

Kasel et al prospectively compared sequential patients treated at a single institution with the CoreValve and SAPIEN devices. Patients treated with TAVI from December 2007 to April 2010 with the CoreValve device; those treated after April 2010 received the SAPIEN device. The present study included 50 patients treated with transfemoral TAVI with each device; of 185 patients considered candidates for TAVI, the first 25 of those treated in the 2007-2010 period were excluded to avoid a learning curve effect. In addition, 60 of those who were treated with transapical TAVI in the post-2010 period were excluded. SAPIEN- and CoreValve-treated patients differed at baseline in relation to sex, history of dyslipidemia, previous cardiovascular surgery, previous chest irradiation, STS score, and presence of rhythm disturbances. Device implantation success rates were similar between groups (98% with the SAPIEN valve vs 90% with the CoreValve; p=0.20). For the primary end point of Valve Academic Research Consortium–combined safety events, in multivariable analysis, the SAPIEN device was associated with significantly fewer AEs (OR=0.21; 95% CI, 0.05 to 0.84; p=0.03). More patients treated with the CoreValve required a permanent pacemaker placement (38% vs 8%; p<0.001).

**Section Summary: Comparisons of Different TAVI Devices**

A single RCT that compared TAVI devices with different mechanisms (self-expanding [CoreValve] valves vs balloon-expandable [SAPIEN] valves) reported no significant differences in cardiovascular mortality at 30 days postprocedure. However, the balloon-expandable valve was associated with higher rates of device success due to lower rates of paraprosthetic regurgitation and with lower rates of permanent pacemaker requirement. These findings are supported by results from
nonrandomized comparisons between the 2 currently available types of TAVI devices.

**Comparisons of Alternative TAVI Approaches**

Most patients treated with TAVI, and all patients enrolled in the PARTNER B trial, have received the valves using the transfemoral approach. Other approaches, such as the transapical approach, have been used in patients with inadequate femoral access. There is limited evidence comparing outcomes for different approaches. In the PARTNER A trial, slightly less than one-third of procedures were performed transapically, and there were no substantial differences in outcomes between approaches. The SAPIEN transcatheter heart-valve system has FDA approval for use by the transfemoral and transapical approach. The CoreValve device has FDA approval for use by the transfemoral, transsubclavian/transaxillary, and transaortic approaches.

**Systematic Reviews**

A meta-analysis of 20 nonrandomized studies comparing outcomes from the transfemoral and transapical approaches was published by Li et al in 2013. This analysis included 20 studies, 19 of which were prospective and 1 of which was retrospective. There were 4267 patients treated by the transfemoral approach and 2242 patients treated by the transapical approach. Patients treated by transfemorally had a lower 30-day mortality (7.5% vs 11.3%). There were no differences between groups in incidence of stroke (3.8% vs 4.0%) or heart block requiring pacemaker (8.5% vs 7.5%).

Garcia et al conducted a meta-analysis comparing 30-day outcomes after TAVI via the transfemoral, transapical, and transsubclavian approaches. The authors included 7 studies with 2636 patients (1526 who received transfemoral access, 882 who received transapical access, 228 who received transsubclavian access). Compared with transfemoral access, transapical access was associated with higher odds of 30-day mortality (OR=1.54; 95% CI, 1.09 to 2.16; p=0.01); all patients studied for this comparison received the SAPIEN valve. Compared with transfemoral access, transsubclavian access was associated with no significant difference in 30-day mortality (OR=0.64; 95% CI, 0.31 to 1.32; p=0.23), but was associated with a decreased risk of vascular complications (OR=0.53; 95% CI, 0.29 to 0.95; p=0.03).

A third meta-analysis compared the transfemoral and transapical approaches in patients who were not eligible for open surgery who underwent TAVI. Seventeen studies with a total of 2978 patients (1465 treated transfemorally, 1513 treated transapically) were included. Similar to the findings reported by Garcia and Li, 30-day all-cause mortality was lower after transfemoral TAVI than after transapical TAVI (pooled OR=0.59; 95% CI, 0.45 to 0.76; p<0.001). In the overall population, all-cause mortality did not differ significantly between groups. However, after modulating by logistic EuroSCORE, 1-year all-cause mortality was significantly lower with the transfemoral approach than with the transapical (OR not reported; p=0.001).
A fourth systematic review and meta-analysis comparing outcomes after transfemoral and transapical TAVI was reported by Liu et al (2015). This review included 9 observational studies with a total of 1123 patients (666 underwent transfemoral implantation, 457 underwent transapical implantation). Patients did not differ significantly by logistic EuroSCORE, although details of how the analysis accounted for the EuroSCORE are not given. In this review, there was no significant difference between treatment approaches in 30-day or 1-year mortality.

Nonrandomized Comparative Studies
Some nonrandomized, comparative studies have evaluated outcomes for the transfemoral approach and alternative approaches. In many, direct comparisons between approaches are difficult given the potential for confounding by between-group differences in patients' underlying disease severity and/or frailty. Studies that compare subgroups of patients who are matched based on propensity score methods help reduce, but not eliminate, this confounding.

Prospective comparisons are available from analyses of PARTNER trial data. Blackstone et al (2015) reported a subanalysis of the PARTNER-I trial comparing outcomes between the transfemoral and the transapical approaches, with propensity score matching of patients to control for some underlying differences in patients treated with the 2 approaches. A total of 2621 high-risk or inoperable patients who underwent transapical TAVI (n=1100) or transfemoral TAVI (n=1521) as part of PARTNER A, PARTNER B, or their continued access studies. Groups differed at baseline, particularly for presence of peripheral artery disease. Patients in the 2 groups were matched based on a propensity score, leading to 501 well-matched pairs. Patients in the matched group treated with a transapical approach had a higher in-hospital mortality than those treated with a transfemoral approach (7.4% vs 2.8%, p=0.001), but did not have a significantly different risk of stroke (2.8% vs 3.2%, p=0.7), all respectively. The probability of death after transapical versus transfemoral TAVI differed the most early after the procedure: 9.1% versus 3.7% at 30 days; 19% versus 12% at 6 months; 26% versus 19% at 1 year; 37% versus 33% at 2 years; and 47% versus 45% at 3 years, all respectively. The difference in mortality rates was statistically significant (p=0.01), early after surgery but not after about 4 months postsurgery.

Before the Blackstone et al publication comparing outcomes transfemoral and transapical TAVI, Dewey et al used data from the transapical cohort of the PARTNER trial combined with data from patients who underwent transapical TAVI in the continued-access study to report outcomes after transapical procedures. Included in their analysis were 104 patients who underwent transapical TAVI as part of the PARTNER trial, 92 patients who had been in the transapical cohort in the PARTNER trial and were randomized to conventional surgical valve repair, and 975 patients who underwent transapical TAVI as part of the continued-access registry. Thirty-day and in-hospital mortality were similar across groups: 10.6% for patients who received transapical TAVI as part of the PARTNER trial; 12.0% for patients who underwent surgical valve repair; and 8.8% for patients who received transapical TAVI as part of the continued-access registry (p=0.54). Compared with those who received transapical TAVI as part of the PARTNER trial, those in the
continued-access registry had a lower rate of stroke at 1 year (3% vs 10.8%; p=0.004).

Another study used data from a prospective single-center registry to compare outcomes for patients who underwent TAVI by a transfemoral (n=587) or transapical (n=413) approach. Decisions about the access route were based on interdisciplinary consensus by members of the heart team. In the full cohort of 1000 patients, patients undergoing TAVI by the transapical route were less often female and had less pulmonary hypertension, but were more likely to have peripheral arterial disease, coronary artery disease, carotid stenosis, and recurrent cardiac surgery. In the full cohort, 30-day mortality, rates of periprocedural MI, and rates of stroke or TIA did not differ significantly between groups. However, those undergoing TAVI by the transfemoral route were more likely to have major vascular complications (17.5% vs 2.4%; OR=0.12; 95% CI, 0.06 to 0.22; p<0.001), major bleeding (6.6% vs 5.6%; OR=0.46; 95% CI, 0.24 to 0.87; p=0.01), a new pacemaker requirement (15.7% vs 10.7%; OR=0.64; 95% CI, 0.44 to 0.94; p=0.02), and moderate aortic insufficiency (3.9% vs 1.2%; OR=0.3; 95% CI, 0.11 to 0.80; p=0.01), all respectively. In a cohort of 708 patients matched by propensity score to adjust for between-group differences, the risk of major vascular complications and moderate aortic insufficiency remained higher in those treated transfemorally, but the differences in rates of major bleeding and new pacemaker requirement were no longer statistically significant.

Multiple retrospective studies have compared outcomes from TAVI with different access routes. They have generally reported higher rates of mortality with transapical TAVI.

Section Summary: Comparisons of Alternative TAVI Approaches

The most direct evidence on TAVI approaches relates to the transapical approach, compared with the more commonly used transfemoral approach. This evidence includes a subgroup analysis from the PARTNER RCT, nonrandomized comparative studies, and systematic reviews of these studies. In the RCT, there was no mortality difference between the 2 approaches. Nonrandomized studies varied by whether the transapical approach was associated with a higher mortality. Patients treated by the transapical approach were more severely ill, with a higher predicted mortality at baseline. It is not possible to determine whether reported mortality differences are due to noncomparability of groups or due to the specific approach. There is very little evidence on other approaches such as the transaxillary, transaortic, and transiliac.

Outcomes for TAVI for “Valve-in-Valve” Approach

TAVI has been used through a “valve-in-valve” replacement approach for patients with degenerated bioprosthetic valves or failed TAVI. The evidence on outcomes after the use of TAVI for “valve-in-valve” replacement consists of case series. The largest case series published to date is from the Global Valve-in-Valve registry. The most recent results from this registry have been reported through May 2013, including 459 patients. Included patients were from 38 cardiac centers who had a prior surgical bioprosthetic valve replacement that had failed. Failure was due to
stenosis in 181 (39.4%) patients, regurgitation in 139 (30.3%), or a combination in 139 (30.3%). The balloon-expandable and self-expandable devices were used in 246 (53.6%) and 213 (46.4%) patients, respectively. At 30 days, mortality was 7.6% (35/459), with a higher mortality rate in patients with failure due to stenosis (10.5% vs 4.3% in the regurgitation group and 7.2% in the combined group; p=0.04). At 30 days, 35 (7.6%) patients had died. Patients in the stenosis group had a higher 30-day mortality rate (10.5% vs 4.3% in the regurgitation group vs 7.2% in the combined group; p=0.04). The overall 1-year mortality rate was 16.8%, with a higher mortality rate in the stenosis group (23.4%) than the other 2 groups (8.8% in the regurgitation group, 16.1% in the combined group; p=0.01). At 1 year, 86.2% of patients were in NYHA functional class I or II.

Other case series are smaller and generally from a single center. A case series from Europe using the CoreValve enrolled 27 patients from 1 cardiology center.65 There were 2 deaths within 30 days. Improvements in the aortic valve gradient and the degree of regurgitation were noted. AEs included stroke (7.4%), kidney failure (7.4%), life-threatening bleeding (7.4%), and access site complications (11.1%). Another case series from Europe treated 18 patients with a degenerated bioprosthetic valve and symptoms due to valve dysfunction.66 Implantation was successful in 17 of 18 patients. Complications included AKI in 3 of 18 patients, major bleeding in 4 of 18 patients, and major access site complications in 1 of 18 patients. At a median follow-up of 11 months, mortality was 5.6% and symptoms were improved with all patients in NYHA class II or lower. A series from Australia, including 12 patients who underwent valve-in-valve replacement of a degenerated bioprosthetic valve, reported successful valve implantation for all patients, with 1 case complicated by cardiac arrest during bioprosthetic valve predilation.67 No periprocedural deaths, MIs, neurologic events, or major vascular complications occurred. After 1624 and 1319 days, respectively, 2 patients had died. The remaining patients had a median survival of 581 days, and all were in NYHA class I or II functional status.

Smaller case series have reported on valve-in-valve implantation for patients with failed TAVI. For example, a publication from Canada reported on 21 patients with transcatheter valve failure due to aortic regurgitation.68 The procedure was successful in 19 of 21 patients; the remaining 2 patients required conversion to open surgery. Mortality at 30 days was 14.3% and was 24% at 1 year. Aortic regurgitation was absent in 4 patients, mild in 13 patients, and moderate in 2 patients.

In 2014, Raval et al reported results from a systematic review of multiple types of valve-in-valve replacement procedures, including 31 studies that evaluated outcomes after transcatheter aortic valve-in-valve replacement, 13 of which were case reports.69 Pooled analyses of study results are not reported, but the reviewers reported a relatively high rate (90%-90%) of success for valve-in-valve TAVI procedures.
Section Summary: Outcomes for TAVI for “Valve-in-Valve” Approach

The evidence related to the use of TAVI for valve-in-valve replacement after failed TAVI or degenerated bioprosthetic valve consists of case series, the largest of which included 459 patients, a systematic review of the available case series. These series have reported high rates of technical success of valve implantation, but often have also reported high rates of short-term complications. At 1 year postprocedure, reported mortality rates are often high, but high proportions of patients have improvement in heart failure–related symptoms.

Complications Following TAVI

Summary of Complications

A 2013 meta-analysis of complications associated with TAVI was published by Khatri et al in 2013. This analysis included all publications with at least 100 patients and with data on at least 1 type of complication. Forty-nine studies (total N=16,063 patients) were identified. The most common AE was heart block requiring a pacemaker insertion, which occurred in 13.1% of patients. Vascular complications occurred in 10.4% of patients. The third most common complication was acute renal failure requiring therapy in 4.9% of patients, followed by moderate-to-severe aortic regurgitation in 4.5%, stroke in 2.9%, valve embolization in 1.3%, MI in 1.1%, and coronary obstruction in 0.8%.

Giordana et al published a meta-analysis of predictors of all-cause mortality after TAVI. They included 25 studies with 8874 patients who underwent TAVI for severe symptomatic aortic stenosis that reported predictors of mortality at 30 days or at mid-term follow-up. Most (51.1%) patients underwent the procedure via the transfemoral approach, with 33.7% and 1.7% receiving a transapical or direct aortic/subclavian approach, respectively. A SAPIEN balloon-expandable valve was used in 5392 (60.8%) patients, while a CoreValve self-expandable valve was used in 1899 (21.4%) patients. Three studies did not report the type of valve implanted. At 30 days, 663 (7.5%) patients, 712 (8.02%) developed AKI, 1224 (13.8%) developed major bleeding, 782 (8.8%) developed major vascular complications, and 1106 (12.5%) required pacemaker implantation. At mid-term follow-up (median, 365 days), 1917 (21.6%) patients had died. The strongest predictors of 30-day mortality were higher AKI stage (≥2; OR=18.0; 95% CI, 6.25 to 52), preprocedural hospitalization for at least 1 week (OR=9.36; 95% CI, 2.55 to 35), periprocedural acute MI (OR=8.54; 95% CI, 2.57 to 33.52), and preprocedural increased pro-brain natriuretic peptide (BNP) levels (OR=5.35; 95% CI, 1.74 to 16.5). The strongest predictors of mid-term mortality were increased pro-BNP levels (OR=11; 95% CI, 1.51 to 81), stage 3 AKI (OR=6.80; 95% CI, 2.55 to 15.66), left ventricular ejection fraction less than 30% (OR=6.67; 95% CI, 3.5 to 12.76), and periprocedural acute MI (OR=6.52; 95% CI, 2.34 to 18.14).

Some studies have specifically reported on 1 or more complications in large numbers of patients. Representative studies of this type will be reviewed here.
**Vascular Access Complications**

The most common complications following TAVI are vascular related to the access site. Van Mieghem et al pooled results from prospective databases on 986 patients undergoing transfemoral TAVI from 5 clinical centers in Europe. The rate of major vascular complications was 14.2%. Major bleeding occurred at a rate of 17.8% and life-threatening/disabling bleeding at a rate of 11%. Czerwinska-Jelonkiewicz et al reported vascular complication rates for 89 consecutive patients treated at a single institution; 44 patients had vascular complications, 17 (20.5%) of which were considered major incidents.

**Acute Kidney Injury**

AKI is relatively common following TAVI. In 218 patients treated at 1 U.S. academic medical center, stage 2 or higher AKI occurred in 8.3% (18/218). Half the patients with AKI (9/18) required dialysis. Mortality at 30 days (44.4% vs 3.0%, p<0.001) and 1 year (55.6% vs 16.0%, p<0.001) were much higher in patients with AKI than in those without AKI, respectively. In a similar study of 248 patients from an academic center in Europe, stage 2 or higher AKI was more common, occurring in 35.9% of patients (89/248). Mortality was also increased at 30 days (13.5% vs 3.8%, p<0.001) and at 1 year (31.5% vs 15.0%, p<0.001) for patients with AKI.

**Permanent Pacemaker Requirement**

A pacemaker requirement due to conduction abnormalities is another relatively frequent complication following TAVI, and predictors and rates of permanent pacemaker requirement have been a focus of a number of studies.

Siontis et al conducted a meta-analysis to determine predictors of permanent pacemaker implantation after TAVI. The authors included 41 studies that made available individual patient-level data, which included 11,210 patients treated with TAVI, of whom 17% required a permanent pacemaker after aortic valve implantation. Between 2% and 51% of patients across the individual studies required a permanent pacemaker. For the patients receiving the CoreValve, the median rate of permanent pacemaker placement was 28% (interquartile range, 24%-35%), whereas for those receiving the SAPIEN valve, the median permanent pacemaker placement rate was 6% (interquartile range, 5%-7%). In pooled analyses, factors significantly associated with permanent pacemaker requirement after TAVI included male sex (RR=1.23, p<0.01), baseline first-degree atrioventricular block (RR=1.52, p<0.01), and intraprocedural atrioventricular block (RR=3.49, p<0.01).

Several studies not included in the Siontis review that have addressed the need for permanent pacemaker placement after TAVI were identified. Gensas et al reported rates and predictors of permanent pacemaker requirements after TAVI in patients enrolled in a multicenter Brazilian registry. Four hundred eighteen patients were treated with TAVI between 2008 and 2012. The authors reported outcomes for 353 who survived the procedure and who did not have a previous permanent pacemaker. A quarter (25.2%) of patients required a permanent pacemaker by 30 days postprocedure. In multivariable analysis, CoreValve device (vs SAPIEN XT;
OR=4.24; 95% CI, 1.56 to 11.49; p<0.000), baseline right bundle branch block (OR=4.41; 95% CI, 2.20 to 8.82; p<0.001), and requirement for balloon predilatation of the aortic valve (OR=1.75; 95% CI, 1.02 to 3.02; p=0.04) were independent predictors of a requirement for permanent pacemaker.

As previously described, Abdel-Wahab et al reported results of an RCT comparing the CoreValve and the SAPIEN valve and found that patients in the balloon-expandable group less frequently required placement of a new permanent pacemaker (17.3% vs 37.6%, p=0.001). 47

Lenders et al compared permanent pacemaker requirement rates based on depth of implantation for patients treated with CoreValve. 77 Two hundred thirty-two patients were treated with CoreValve, some with a newer-generation delivery catheter (the AccuTrak; n=112) and some with an older-generation delivery catheter (n=120). Groups were similar at baseline. Mean depth of implantation was 8.4 mm in the non-AccuTrak group and 7.1 mm in the AccuTrak group (p=0.034). In patients without a permanent pacemaker before valve implantation, 33 (32.3%) patients in the non-AccuTrak group received a permanent pacemaker after implantation, compared with 21 (21.4%) in the AccuTrak group (p=0.094). Among all patients, the mean depth of implantation was significantly lower (lower in relation to a reference line connecting the lower edges of the 3 aortic valve cusps) in patients who required a new permanent pacemaker compared with those who did not (8.9 mm vs 6.9 mm; p=0.002).

Boerlage-Van Dijk et al reported predictors of cardiac conduction abnormalities in 121 patients who received a CoreValve implant at a single center between October 2007 and June 2011. 78 For the analysis of new left bundle branch block, 34 patients were excluded because of preprocedural left bundle branch block or a ventricular-paced rhythm. For the analysis of permanent pacemaker implantation, 16 patients were excluded, 10 patients because of preprocedural pacemaker implantation, 5 because they died before the required observation period for possible pacemaker indication, and 1 because the patient needed a pacemaker implantation due to a sick sinus syndrome, which was unrelated to TAVI and discovered during observation after TAVI. After the TAVI procedure, 23 (21.9%) patients required pacemaker implantation, most commonly due to total atrioventricular block (n=21 [91.3%]). Forty-seven patients developed a new left bundle branch block after the TAVI procedure, which was temporary in 19%. Significant predictors of pacemaker requirement were mitral annular calcification and preexisting right bundle branch block, while prosthesis size and prosthesis depth were significant predictors of new left bundle branch block.

In another series reporting on predictors of cardiac conduction abnormalities after CoreValve implantation, Kim et al reported on 117 patients without preexisting permanent pacemakers who underwent CoreValve placement, of whom 12 required a pacemaker postimplantation. 79 In multivariable analysis, the strongest predictors of pacemaker requirement were the perimeter stretching index (OR=1.548; 95% CI, 1.239 to 1.935; p<0.001) and the device depth (OR=1.262; 95% CI, 1.034 to 1.543, p=0.02).
Section Summary: Complications Following TAVI
In addition to complication rates reported in randomized and nonrandomized studies evaluating outcomes after TAVI, 2 meta-analyses and a number of cohort studies have reported specifically on complications after TAVI, particularly vascular access complications, AKI, and need for permanent pacemaker. Given the high requirements for new permanent pacemakers after TAVI, particularly with the CoreValve, studies have focused on predictors of new conduction abnormalities, identifying the use of a CoreValve device (vs the SAPIEN device), insertion depth, and preexisting right bundle branch block as significant predictors of pacemaker requirement.

Ongoing and Unpublished Clinical Trials
Some currently unpublished trials that might influence this review are listed in Table 1.

Table 1. Summary of Key Trials

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<td>NCT01314313a</td>
<td>The PARTNER II Trial &quot;Placement of AoRTic TraNsCathetER Valves Trial&quot; (US) [Edwards Study 2010-12]</td>
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<td>NCT02163850a</td>
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NCT: national clinical trial.
a Denotes industry-sponsored or cosponsored trial.

Summary of Evidence
For individuals who have severe symptomatic aortic stenosis who are at prohibitive risk for open surgery who receive transcatheter aortic valve implantation (TAVI), the evidence includes 1 randomized controlled trial (RCT) comparing TAVI with medical management in individuals at prohibitive risk of surgery, and multiple case
series. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. For patients who are not surgical candidates due to excessive surgical risk, the PARTNER B trial reported results for patients treated with TAVI by the transfemoral approach compared to continued medical care with or without balloon valvuloplasty. There was a large decrease in mortality for the TAVI patients at 1 year compared with medical care. This trial also reported improvements on other relevant clinical outcomes for the TAVI group. There was an increased risk of stroke and vascular complications in the TAVI group. Despite these concerns, the overall balance of benefits and risks from this trial indicate that health outcomes are improved. For patients who are not surgical candidates, no randomized trials have compared the self-expandable valve with best medical therapy. However, results from the single-arm CoreValve Extreme Risk Pivotal Trial met the authors’ prespecified objective performance goal. The evidence is sufficient to determine qualitatively that the technology results in a meaningful improvement in the net health outcome.

For individuals who have severe symptomatic aortic stenosis who are at high risk for open surgery who receive TAVI, the evidence includes 2 RCTs comparing TAVI with surgical repair in individuals at high risk for surgery, and multiple nonrandomized comparative studies and systematic reviews of these studies. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. For patients who are high risk for open surgery and are surgical candidates, the PARTNER A trial reported noninferiority for survival at 1 year for the balloon-expandable valve compared with open surgery. In this trial, TAVI patients also had higher risks for stroke and vascular complications. Nonrandomized comparative studies of TAVI versus open surgery in high-risk patients have reported no major differences in rates of mortality or stroke between the 2 procedures. Since publication of the PARTNER A trial, the CoreValve High Risk Trial demonstrated noninferiority for survival at 1 year for the self-expanding prosthesis. This trial reported no significant differences in stroke rates between groups. In an RCT directly comparing the self-expandable with the balloon-expandable valve among surgically high-risk patients, the devices had similar 30-day mortality outcomes, although the self-expandable valve was associated with higher rates of residual aortic regurgitation and requirement for a new permanent pacemaker. Evidence from RCT and nonrandomized studies has suggested that TAVI with a self-expanding device is associated with higher rates for permanent pacemakers postprocedure. However, survival rates appear to be similar between device types, and the evidence does not clearly support the superiority of 1 device over another in all patients. The evidence is sufficient to determine qualitatively that the technology results in a meaningful improvement in the net health outcome.

For individuals who have severe symptomatic aortic stenosis who are at low or intermediate risk for open surgery who receive TAVI, the evidence includes 2 RCTs comparing TAVI with surgical repair in individuals selected without specific surgical risk criteria. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. One investigator-initiated RCT reported no significant difference in the composite rates of death, stroke, or
myocardial infarction at 1 year between patients treated with TAVI or with open surgical repair. The rates of adverse events differed between groups, with bleeding, cardiogenic shock, and acute kidney injury higher in patients randomized to open surgery and permanent pacemaker requirement higher in patients randomized to TAVI. A second study was terminated early due to unexpectedly high rates of adverse events in the TAVI arm; it did not report any data on efficacy outcomes. Further RCT evidence in this population is needed to determine the efficacy of TAVI compared to surgery, to better define the early adverse event rate, and to determine whether TAVI is as good as surgery in the longer term. The evidence is insufficient to determine the effects of the technology on health outcomes.

For individuals who have valve dysfunction and aortic stenosis or regurgitation after aortic valve repair who receive transcatheter aortic “valve-in-valve” implantation, the evidence includes case series (largest included 459 patients) and systematic reviews of case series. Relevant outcomes are overall survival, symptoms, morbid events, and treatment-related mortality and morbidity. These case series have reported high rates of technical success of valve implantation, and improvement in heart-failure symptoms for most patients. However, they have also reported high rates of short-term complications and high rates of mortality at 1 year postprocedure. There is a lack of evidence comparing valve-in-valve replacement with alternative treatment approaches. The evidence is insufficient to determine the effects of the technology on health outcomes.

**Supplemental Information**

**Clinical Input Received From Physician Specialty Societies and Academic Medical Centers**

While the various physician specialty societies and academic medical centers may collaborate with and make recommendations during this process, through the provision of appropriate reviewers, input received does not represent an endorsement or position statement by the physician specialty societies or academic medical centers, unless otherwise noted.

**2016 Input**

In response to requests, clinical input was received from 2 specialty societies (1 of which provided 2 responses) and 2 academic medical centers (1 of which provided 3 responses) while this policy was under review in 2016. Although there was no support for the use of valve-in-valve TAVI to replace a failed bioprosthetic valve in general use, there was general support for the use of valve-in-valve TAVI for patients at high and prohibitive risk for surgery.

**2014 Input**

In response to requests, clinical input was received from 2 specialty societies (1 of which provided 2 responses) and 6 academic medical centers while this policy was under review in 2014. All reviewers who provided a response considered TAVI medically necessary for patients with severe aortic stenosis with a calcified aortic annulus and New York Heart Association functional class II, III, or IV symptoms,
and who are not operable candidates for open surgery or who are operable candidates but are at high risk for open surgery. Most reviewers would require a patient to have a left ventricular ejection fraction greater than 20% for the procedure to be medically necessary. All reviewers indicated support for limiting the use of TAVI to patients who are not operable candidates for open surgery or who are operable candidates but are at high risk for open surgery, and most supported using the Food and Drug Administration’s (FDA) definition of high risk and extreme risk for surgery. Most reviewers noted that self-expanding valves have been associated with higher rates of postprocedural pacemaker requirements but that neither type of valve was clearly superior to the other.

2011 Input
In response to requests, clinical input was received from 1 specialty society and 6 academic medical centers while this policy was under review in 2011. At the time of vetting, FDA approval had not yet been granted for any TAVI device. Reviewers were mixed in support for a medically necessary indication for patients who are not surgical candidates. However, all reviewers indicated that they would consider this procedure medically necessary if FDA granted approval. None of the reviewers expressed support for medical necessity in other patient populations, including patients who were at high risk for surgery, but were surgical candidates. Concerning patient selection criteria, most reviewers referred to the study selection criteria in the PARTNER trial and did not offer further options for objective patient selection.

Practice Guidelines and Position Statements

American Heart Association and American College of Cardiology
In 2014, the American Heart Association and the American College of Cardiology published guidelines for the management of valvular heart disease. These guidelines made the following recommendations on the choice of surgical or transcatheter intervention for treatment of aortic stenosis:

- **Class I recommendations:**
  - “Surgical AVR [aortic valve replacement] is recommended in patients who meet an indication for AVR with low or intermediate surgical risk.” (Level of Evidence: A)
  - “For patients in whom TAVR [transcatheter aortic valve replacement] or high-risk surgical AVR is being considered, members of a Heart Valve Team should collaborate to provide optimal patient care” (Level of Evidence: C)
  - “TAVR is recommended in patients who meet an indication for AVR for AS [aortic stenosis] who have a prohibitive surgical risk and a predicted post-TAVR survival >12 mo.” (Level of Evidence: B)

- **Class IIa recommendations:**
  - “TAVR is a reasonable alternative to surgical AVR in patients who meet an indication for AVR and who have high surgical risk.” (Level of Evidence: B)

- **Class IIb recommendations:**
“Percutaneous aortic balloon dilation may be considered as a bridge to surgical or transcatheter AVR in severely symptomatic patients with severe AS.” (Level of Evidence: C)

- **Class III recommendations (no benefit):**
  - “TAVR is not recommended in patients in whom existing comorbidities would preclude the expected benefit from correction of AS.” (Level of Evidence: B)

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**European Society for Cardiology and European Association for Cardio-Thoracic Surgery**

In 2012, the European Society for Cardiology and the European Association for Cardio-Thoracic Surgery published guidelines on the management of valvular heart disease. These guidelines made the following recommendations on the use of TAVI:

- **Class I recommendations:**
  - “TAVI should only be undertaken with a multidisciplinary ‘heart team’ including cardiologists and cardiac surgeons and other specialists if necessary.” (Level of Evidence: C)
  - “TAVI should only be performed in hospitals with cardiac surgery on-site.” (Level of Evidence: C)
  - “TAVI is indicated in patients with severe symptomatic AS who are not suitable for AVR as assessed by a ‘heart team’ and who are likely to gain improvement in their quality of life and to have a life expectancy of more than 1 year after consideration of their comorbidities.” (Level of Evidence: B)

- **Class IIa recommendations:**
  - “TAVI should be considered in high-risk patients with severe symptomatic AS who may still be suitable for surgery, but in whom TAVI is favoured by a ‘heart team’ based on the individual risk profile and anatomic suitability.” (Level of Evidence: B).

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**American College of Cardiology Foundation and Society of Thoracic Surgeons**

A professional society overview on transcatheter valve therapy was published 2011 by the American College of Cardiology Foundation and the Society of Thoracic Surgeons. This document enumerated the core issues anticipated in integrating TAVI into general clinical care. As part of this document, a list of necessary components for the successful introduction of transcatheter heart valve therapies was developed:

- “Specialized heart centers with experienced multidisciplinary physicians and paramedical personnel
- “The professional multidisciplinary heart team:
  - Primary cardiologists
  - Cardiac surgeons
  - Interventional cardiologists
  - Echocardiographers and imaging specialists
Heart failure specialists

- “Proper procedure and facilities
  - Modified conventional cardiac laboratory
  - Hybrid operating room
- “Development of and participation in clinical database and registries
- “Knowledge of, and evaluation of, evidence-based medical literature concerning patient selection, procedural performance, and complication management
- “Specific standardized protocols for management strategies, procedural performance, problem-solving, and complication management
- “Appropriate ongoing personnel training”

U.S. Preventive Services Task Force Recommendations
Not applicable.

Medicare National Coverage
The Centers for Medicare and Medicaid Services (CMS) published a decision memo on the use of transcatheter aortic valve replacement (TAVR) in May 2012. This memo indicated that CMS covers TAVI when used according to FDA indications when the following conditions are met:

- Device has FDA approval
- Two cardiac surgeons agree with indications for the procedure
- The patient is under the care of a heart team, and the hospital meets qualifications for performing TAVR.

The memo also stated that TAVR could be covered for non-FDA-approved indications under the Coverage with Evidence Development (CED) program. The following is a summary of the main conditions required for CED:

- TAVI is performed within a clinical study that has the following characteristics:
  - The clinical study must adhere to the standards of scientific integrity and relevance to the Medicare population.
  - The study must address quality of life and adverse events at follow-up periods of 1 year or longer.

References
4. Bonow RO, Carabello BA, Kanu C, et al. 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 (writing committee to revise the 1998 Guidelines for the Management of Patients With Valvular Heart Disease): developed in collaboration with the Society of Cardiovascular Anesthesiologists: endorsed by the Society for...


### Billing Coding/Physician Documentation Information

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</tr>
<tr>
<td>33364</td>
<td>Transcatheter aortic valve replacement (TAVR/TAVI) with prosthetic valve; open iliac artery approach</td>
</tr>
<tr>
<td>33365</td>
<td>Transcatheter aortic valve replacement (TAVR/TAVI) with prosthetic valve; transaortic approach (eg, median sternotomy, mediastinotomy)</td>
</tr>
<tr>
<td>33366</td>
<td>Transcatheter aortic valve replacement (TAVR/TAVI) with prosthetic valve; transapical exposure (eg, left thoracotomy)</td>
</tr>
<tr>
<td>33367</td>
<td>Transcatheter aortic valve replacement (TAVR/TAVI) with prosthetic valve; cardiopulmonary bypass support with percutaneous peripheral arterial and venous cannulation (eg, femoral vessels) (List separately in addition to code for primary procedure)</td>
</tr>
<tr>
<td>33368</td>
<td>Transcatheter aortic valve replacement (TAVR/TAVI) with prosthetic valve; cardiopulmonary bypass support with open peripheral arterial</td>
</tr>
</tbody>
</table>
and venous cannulation (eg, femoral, iliac, axillary vessels) (List separately in addition to code for primary procedure)

33369  Transcatheter aortic valve replacement (TAVR/TAVI) with prosthetic valve; cardiopulmonary bypass support with central arterial and venous cannulation (eg, aorta, right atrium, pulmonary artery) (List separately in addition to code for primary procedure)

93591  Percutaneous transcatheter closure of paravalvular leak; initial occlusion device, aortic valve (new code 1/1/2017)

93592  Percutaneous transcatheter closure of paravalvular leak; each additional occlusion device (List separately in addition to code for primary procedure) (new code 1/1/2017)

**ICD-10 Codes**

I06.0- I06.9  Rheumatic aortic valve diseases
I08.0; I08.2- I08.9  Multiple valve diseases involving aortic valve
I35.0- I35.9  Nonrheumatic aortic valve disorders (I35.0 is nonrheumatic aortic valve stenosis and I35.2 is nonrheumatic aortic valve stenosis with insufficiency)

T82.01xA- T82.09xS  Mechanical complication of heart valve prosthesis code range
T82.857A; T82.857D; T82.857S  Stenosis of other cardiac prosthetic devices, implants and grafts code list

Prior to 2013, there were category III CPT codes for this procedure: 0256T, 0257T, 0258T, 0259T.

**Additional Policy Key Words**

N/A

**Policy Implementation/Update Information**

2/1/12  New policy; considered medically necessary for patients who are not surgical candidates; investigational for all other indications

2/1/13  Medically necessary indications added for patients who are at high risk for open surgery using the transfemoral approach, and patients who are at high risk for open surgery using the transapical approach. Investigational statement added for treatment of degenerated bioprosthetic valve or failed TAVI (Valve-in-Valve approach), and for vascular approaches other than transfemoral or transapical

2/1/14  Policy statement revised to include medically necessary indication for TAVI by the transapical approach for patients who are not suitable candidates for open surgery.

12/1/14  Policy statement revised to remove statement that “procedures performed via the transaxillary, transiliac, transaortic, or other approaches” are investigational, to reflect the approval of the CoreValve
device that is labeled for use via transaxillary, transfemoral, and transaortic approaches. A statement was added to the policy statement that devices should be used according to their FDA approved indication. Clinical input supported proposed policy statements.

2/1/15 No policy statement changes.
2/1/16 No policy statement changes.
10/1/16 Medically necessary policy statement added for valve-in-valve implantation in patients at high or prohibitive risk for open surgery.
2/1/17 No policy statement changes.

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