Keynote Lecture Series

Surgical versus transcatheter aortic valve replacement: the future role of robotic aortic valve replacement

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Patients desire a minimally invasive option for management of their valve disease. As transcatheter aortic valve replacement (TAVR) remains a straightforward short-term solution, it is incumbent upon surgeons to provide an alternative, and preferably non-sternotomy or anterior chest option with the longitudinal benefits of surgical aortic valve replacement (SAVR). The present review will focus on the novel use of robotic aortic valve replacement (RAVR) via right lateral transaxillary mini-thoracotomy to perform standard SAVR, which permits the additional ability to perform concomitant procedures using the standard lateral approach popularized in mitral and atrial fibrillation surgery. We will define a role for RAVR in the current landscape of TAVR to provide a minimally invasive and durable operation, allowing for performance of concomitant procedures. Furthermore, we will focus on current literature supporting the safe and stepwise expansion of RAVR worldwide to provide patients requiring aortic valve replacement another option.

Keywords: Robotic aortic valve replacement (RAVR); surgical aortic valve replacement (SAVR); transcatheter aortic valve replacement (TAVR)

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Minimally invasive surgical aortic valve replacement (SAVR)

A recent Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database (ACSD) analysis highlighted excellent early outcomes with a 93% five-year survival in 42,586 low-risk patients undergoing isolated SAVR (1). The incidence of minimally invasive approaches to SAVR from the STS ACSD is 20%, including both hemi-sternotomy and right anterior thoracotomy (2). A recent meta-analysis of minimally invasive SAVR highlighted a risk-adjusted lower incidence of postoperative atrial fibrillation (AF) and shorter length of stay but no difference in stroke or operative mortality compared to conventional SAVR (3) (*Table 1*). However, there remain important limitations to these minimally invasive approaches. First, the use of sutureless valves has been linked to the expanded use of right anterior thoracotomy, but these devices may have the same durability and paravalvular leak (PVL) concerns as transcatheter valves. Additionally, the limited visualization and access to the heart preclude performance of concomitant procedures, including surgical ablation for AF, mitral or tricuspid valve surgery, or coronary artery bypass. Finally, these minimally invasive approaches are typically not considered in the setting of re-operative cardiac surgery.

Transcatheter aortic valve replacement (TAVR)

The advent of TAVR has led to rapid widespread expansion for treatment of severe symptomatic aortic stenosis (AS). Contemporary data support equipoise between SAVR and TAVR for the management of symptomatic severe AS across the spectrum of surgical risk as quantified by STS Predicted Risk of Mortality (PROM). In 2019,

Table 1 Minimally invasive *vs.* conventional surgical aortic valve replacement

Publications	n	Mortality	Stroke	POAF	LOS
Calle-Valda 2017, Spain (4)	100	0.18 (0.02, 1.63)	3.06 (0.12, 76.95)	0.05 (0.01, 0.38)	–1.4 (–3.8, 1.0)
Semsroth 2017, Italy/Austria (5)	236	0.65 (0.18, 2.38)	1.0 (0.06, 16.18)	–	–
Magruder 2016, USA (6)	165	1.0 (0.02, 50.98)	–	0.65 (0.34, 1.24)	0.5 (–1.3, 2.3)
Dalén 2016, Sweden (7)	342	0.75 (0.16, 3.38)	2.02 (0.37, 11.20)	–	–
Attia 2016, UK (8)	614	0.66 (0.19, 2.37)	–	–	–1.0 (–1.2, –0.8)
Shehada 2015, Germany (9)	1,170	0.90 (0.36, 2.23)	0.68 (0.31, 1.48)	0.93 (0.43, 1.99)	–1.0 (–1.1, –0.9)
Ariyaratnam 2015, UK (10)	248	0.66 (0.19, 2.37)	–	1.37 (0.80, 2.35)	1.8 (–0.4, 4.0)
Neely 2014, USA (11)	1,104	0.73 (0.36, 1.47)	0.74 (0.35, 1.59)	1.28 (0.78, 2.10)	–1.0 (–1.1, –0.9)
Merk 2014, Germany (12)	954	0.18 (0.04, 0.90)	–	1.83 (1.31, 2.56)	0.6 (–0.2, 1.4)
Furukawa 2014, Germany (13)	808	1.0 (0.25, 4.03)	0.80 (0.21, 2.99)	1.10 (0.79, 1.53)	0.0 (-0.8, 0.8)
Johnston 2012, USA (14)	2,689	1.0 (0.37, 2.68)	1.00 (0.43, 2.32)	–	0.0 (-0.1, 0.1)
Summary		0.77 (0.58, 1.02)	0.79 (0.56, 1.10)	0.67 (0.52, 0.86)	–0.9 (–1.3, –0.5)

Mortality, stroke and POAF is listed as risk adjusted odds ratio, LOS is presented as mean difference in days. POAF, post-operative atrial fibrillation; LOS, length of stay.

Table 2 Transcatheter *vs.* surgical aortic valve replacement

Publications	n	Early mortality	Late mortality	HF readmission	PPM
PARTNER 1, 2015 (19)	699	0.88 (0.65, 1.19)	1.15 (0.86, 1.54)	1.37 (0.80, 2.35)	1.25 (0.67, 2.32)
CoreValve, 2018 (20)	797	0.73 (0.51, 1.04)	1.17 (0.89, 1.54)	1.28 (0.78, 2.10)	2.17 (1.51, 3.11)
PARTNER 2A, 2020 (21)	2,032	0.94 (0.74, 1.19)	1.24 (1.03, 1.49)	1.83 (1.31, 2.56)	1.16 (0.88, 1.54)
SURTAVI, 2021 (22)	1,746	0.93 (0.63, 1.37)	1.02 (0.80, 1.30)	1.10 (0.79, 1.53)	3.38 (2.62, 4.36)
UK TAVI, 2022 (23)	913	0.69 (0.38, 1.25)	–	–	2.05 (1.43, 2.94)
Notion, 2021 (24)	280	0.67 (0.28, 1.60)	1.06 (0.62, 1.81)	–	15.83 (5.06, 49.52)
PARTNER 3, 2020 (25)	950	0.41 (0.14, 1.20)	–	–	1.39 (0.85, 2.27)
Evolut, 2022 (18)	1,468	0.78 (0.39, 1.56)	–	–	–
Summary		0.85 (0.74, 0.98)	1.15 (1.03, 1.29)	1.38 (1.07, 1.78)	2.13 (1.39, 3.27)

HF, heart failure; PPM, permanent pacemaker.

favorable one year results from the PARTNER 3 low-risk (Safety and Effectiveness of the Sapien 3 Transcatheter Heart Valve in Low-Risk Patients with Aortic Stenosis) with a balloon-expandable valve (BEV), and Evolut LR (Evolut Low Risk) with a self-expanding valve (SEV), led to regulatory approval for TAVR in low STS risk (15,16). Five-year outcomes from PARTNER 3 and 4-year Evolut LR trials highlighted similar midterm durability (17,18). A recent meta-analysis of the clinical trial data highlighted TAVR was associated with lower early mortality but higher incidence of early pacemaker, as well as late heart failure rehospitalization and mortality (*Table 2*) (26).

Recommendations from the 2020 American College of Cardiology/American Heart Association (ACC/AHA) and the 2021 European Society of Cardiology/European Association for Cardiac and Thoracic Surgery (ESC/

Table 3 Literature review of robotic aortic valve replacement

Publications	Patients	Mortality	Stroke	Reoperation	PPM	PVL
Badhwar, 2021 (33)	20	0%	0%	0%	0%	0%
Wei, 2022 (34)	50	0%	0%	0%	0%	0%
Badhwar, 2024 (35)	212	2 (0.9%)	2 (0.9%)	16 (7.6%)	5 (2.9%)	4 (1.9%)
Wei, 2024 (in press)	300	2 (0.7%)	3 (1.0%)	25 (8.3%)	7 (2.7%)	7 (2.3%)

PPM, permanent pacemaker; PVL, paravalvular leak.

EACTS) differ slightly with both highlighting age as the principal criteria in addition to importance of the multidisciplinary heart team (MDHT) consensus (27,28). The ACC/AHA guidelines cite for age less than 65 years or life expectancy greater than twenty years to recommend SAVR. For TAVR, the recommendation is for patients age greater than 80 years old or life expectancy of less than ten years. The ESC/EACTS respectively cite age less than 75 years and low surgical risk for SAVR and all patients 75 years or older for TAVR. These dicta are expectedly qualified by the importance of the MDHT consensus, taking into consideration STS PROM risk, overall clinical and functional status, individual patient anatomy, patient preferences, frailty, and futility.

With low-risk TAVR approval, enthusiasm behind a "TAVR for all" approach continues to grow. A California-based study examined 2,360 patients 60 years and younger undergoing aortic valve intervention. In the study period between 2013 and 2021, annual TAVR rate increased from 7.2% to 45.7%, and an annual increase of about 5%. Within this cohort, 358 propensity-matched pairs demonstrated significantly increased five-year all-cause mortality for TAVR [hazard ratio (HR) 2.5, P=0.02]. There was no difference in secondary outcomes, including reoperation, stroke, endocarditis, and heart failure readmission. In 2022, 51.7% of patients less than 65 years old underwent TAVR, the first time in any report that TAVR became the dominant modality in this age group. This was an increase of 272% from the year before in 2021 (29).

A consequence of this shift in practice has been the rise of surgical TAVR explantation due to structural valve degeneration (SVD) of the TAVR prosthesis, now the fastest growing operation in the United States, as noted by the STS ACSD (30). Surgical TAVR explantation incurs an increased chance of requiring aortic intervention, necessitating a more complex operation that carries higher morbidity. A review of 269 patients undergoing TAVR explantation as part of a dedicated multicenter, international registry (EXPLANT-TAVR) (31), over 25% of the patients were deemed low surgical risk at the time of index TAVR, with equal representation of both BEV and SEV. Indications for TAVR explant included endocarditis (43.1%), SVD (20.1%), PVL (18.2%), and patient-prosthesis mismatch (10.8%). Aortic root replacement was performed in 13.4% and 54.6% had concomitant cardiac procedures at the time of TAVR explant. In-hospital mortality was 11.9% and at one year was 28.5%, suggesting a procedure with significant risk. Stratified by initial SEV versus BEV for the initial TAVR, there was no difference in mortality and stroke at one year. The international EXPLANTORREDO-TAVR global registry examined 396 patients, 181 of whom underwent TAVR explantation and 215 who underwent redo-TAVR. TAVR-explant had a higher mortality at thirty days (13.6% *vs.* 3.4%, P<0.001) and one year (32.4% *vs.* 15.4%, P<0.0001) (32). Given these limitations for TAVR, robotic aortic valve replacement (RAVR) serves an important role in the MDHT discussion of the management of symptomatic severe aortic stenosis.

RAVR

In an effort to maintain the technical aspects of traditional prosthetic SAVR, facilitate options for concomitant operations, and to reduce invasiveness even further, transaxillary lateral mini-thoracotomy endoscopic RAVR has been introduced as an alternative option for aortic valve replacement (*Table 3*) (33-35).

Surgical technique

The detailed surgical technique has been previously described. Briefly, all patients receive upper extremity arterial monitoring, central access, and double-lumen endotracheal intubation. Cardiopulmonary bypass is managed via peripheral cannulation established through the right common femoral artery and vein, as well as the right internal jugular vein. An aortic root vent is placed through a 3 cm working incision (*Figure 1*), followed by a left ventricular vent through the right superior pulmonary vein. A transthoracic aortic cross-clamp is then placed, and antegrade cardioplegic solution is delivered via the aortic root and/or directly via the coronary ostia every twenty minutes. A DaVinci Xi robot (Intuitive Surgical, Sunnyvale, CA, USA) is used with the camera port through the working incision (arm 2). Three additional ports include Debakey forceps (arm 1), long-tip grasping forceps (arm 3), and scissors/needle driver (arm 4) (*Figure 1*). A transverse aortotomy in a slightly modified fashion at or above the sino-tubular junction extending down to the midpoint of the noncoronary sinus provides excellent visualization of the aortic valve (*Figure 2*). We utilize the robotic curved scissors and long-tip grasping forceps in all cases to facilitate the debridement of leaflets and all calcific debris with excellent table-side assistance. Circumferential interrupted 2-0 braided polyester sutures are robotically placed from the ventricular side, starting from the left non-commissure and proceeding clockwise. Once annular suture placement is completed, sizing is performed using conventional sizers. The prosthesis is then brought into the field, and the sutures are passed through the ring cuff by the tableside assistant. Once completed, the prosthesis is brought down via the working incision after it has been removed from the handle to facilitate careful annular placement around the aortotomy. Suture fasteners (Cor-Knot; LSI Solutions, Victor, NY, USA) facilitate securing the valve in place (*Figure 2*). The aortotomy is then closed utilizing 4-0 polypropylene sutures in two layers in a

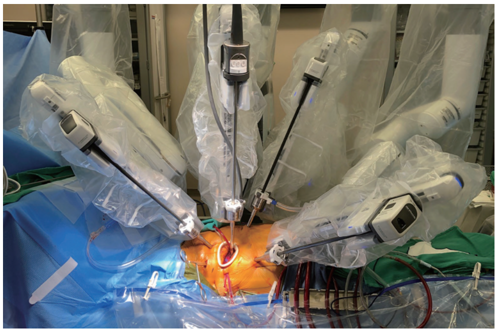

Figure 1 Robotic aortic valve replacement platform.

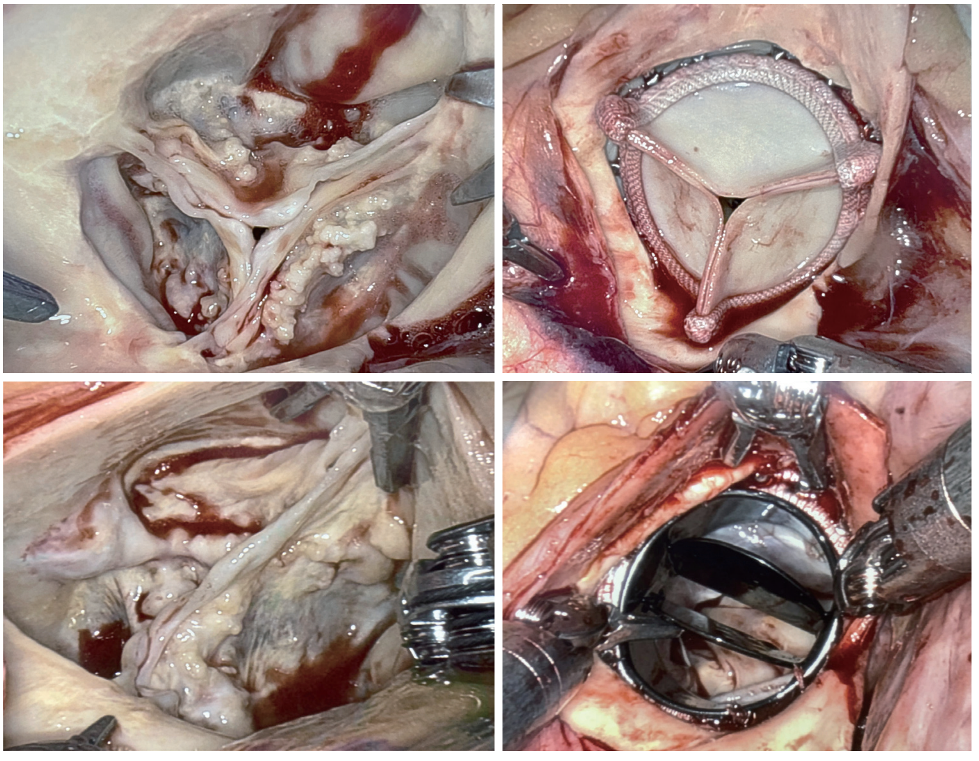

Figure 2 Intraoperative robotic aortic valve replacement with bioprosthetic or mechanical valve.

standard fashion. All patients receive atrial and ventricular pacing wires. The heart is reanimated, the cross-clamp is released, and the patient is weaned from cardiopulmonary bypass, decannulated, and closed.

Clinical outcomes

With the inception of RAVR on January 10th, 2020, the first report was published in 2021, followed by a series on outcomes of the first fifty cases (33,34). A total of 43 cases were for primary pathology of AS, with a collective average STS PROM of 1.5%. Different from the inclusion criteria of the low-risk TAVR trials, the study population had a broader range of ejection fraction (EF) between 25% to 73%, aortic root and left-ventricular outflow tract (LVOT) calcification, and predominant bicuspid anatomy (BAV). Mechanical prostheses were used in 32% of cases, and seven cases also underwent concomitant procedures. At thirty days, there was no major morbidity, mortality, stroke, or PVL.

Recently, a multicenter report of 212 RAVR cases was reported, including follow-up up to one year (35). Median cross-clamp time was 117 minutes and median cardiopulmonary bypass time was 166 minutes. Biological prostheses were implanted in 71.2% and mechanical prostheses in 28.8%. 10.8% underwent aortic root enlargement, 16.5% underwent other procedures, including left atrial appendage obliteration (LAAO) with or without biatrial Cox Maze, patient foramen ovale (PFO) closure, septal myectomy, mitral valve repair (MVr) or mitral valve replacement (MVR). There were no operative conversions to sternotomy. Operative mortality was low at 0.9%. At thirty-day follow-up, all patients reported New York Heart Association (NYHA) class I to II status. A total of 201 patients had completed thirty-day transthoracic echocardiograms (TTEs), which showed a median AV mean gradient (MG) of 10 mmHg and only one patient had worse than trace PVL. New pacemaker rate was 2.8%. Just more than half of the cohort completed one-year clinical and echocardiographic follow-up. Of those that did, median MG was 11 mmHg, with only two patients having worse than 1+ PVL. These favorable results from the first multicenter experience continue to grow with the addition of more centers through the rigorous establishment of training recommendations and curricula to become a RAVR center.

The first propensity-matched comparative analyses between RAVR and TAVR evaluated 288 severe AS patients in two well-balanced groups (144 RAVR and 144 TAVR) of low to intermediate STS risk (36). TAVR was associated with significantly higher rates of new permanent pacemaker [11 (7.6%) *vs.* 3 (2.1%), P=0.028] and vascular complications [13 (9.0%) *vs.* 0 (0.0%), P<0.0001], and an observed trend of higher stroke rate [6 (4.2%) *vs.* 1 (0.7%), P=0.056]. There was no difference in short-term mortality, perioperative stroke, bleeding, or AF. At one year, there was no significant difference in valvular MG. However, one-year mortality [18 (12.5%) *vs.* 2 (1.4%), P<0.0001] and PVL greater than mild [47 (32.6%) *vs.* 2 (2.3%), P<0.0001] were significantly higher in TAVR. Though an observational, retrospective, single-center study, this first comparative effort between TAVR and RAVR helps to inform the MDHT discussion of the optimal approach to aortic valve replacement in the low- to intermediate-risk patient with symptomatic severe AS.

RAVR *vs.* TAVR

Echocardiographic outcomes

Acute echocardiographic outcomes post-valve implantation have important implications on valve durability and intermediate- to long-term clinical outcomes. Low-risk, intermediate-term follow-up data demonstrated similar MG findings but worse paravalvular regurgitation/leak in the TAVR group. PARTNER 3 five-year data demonstrated similar gradients and valve areas between the two arms, with much higher rates of mild or greater PVL (20.8% *vs.* 3.2%) in TAVR (17). Evolut low-risk trial demonstrated lower gradients and larger valve areas, likely owing to the supra-annular prosthesis design. At four years, 84.7% of TAVR patients had no/trace PVL compared with 98.4% with SAVR (18). These highly select clinical trial contexts contrast with real-world observations with respect to moderate or greater PVL. The FinnValve registry analyzed 2,130 TAVR patients and 4,333 SAVR patients with respect to PVL. The rate of mild PVL was 21.7% after TAVR and 5.2% after SAVR, but this was not an independent predictor of survival. However, moderate or severe PVL rates were higher (3.7% in TAVR and 0.7% after SAVR), with an overall significantly worse four-year survival in the TAVR cohort [48.9%, adjusted HR 1.61, 95% confidence interval (CI): 1.10–2.35] (37). In addition, data from the France-TAVI registry reviewing over 20,000 patients demonstrated that PVL ≥2+ over a 6.5-year follow-up was an independent predictor of mortality (38).

An analysis of 914 TAVR patients associated moderate or severe PVL with major adverse events defined as a composite of all-cause death, stroke, or HF hospitalization. Analyses of these patients' computed tomographic (CT) imaging studies identified significant predictors of moderate or severe PVL as a larger virtual raphe ring perimeter, severe annular or LVOT calcification, SEV, and intentional supra-annular TAVR positioning (39). PVL has an important impact on at least intermediate-term hard clinical endpoints. Therefore, PVL is a germane consideration in the management of the lower-risk patient, and RAVR in this context may provide a viable alternative to mitigate PVL and its potential impact on longitudinal patient outcomes.

Pacemaker risk

The new pacemaker rate at four-year follow-up for the Evolut low-risk trial was 24.6% in TAVR versus 9.9% in SAVR (18). The RAVR experience, as mentioned earlier, reported a new pacemaker rate of just under 3%. Data thus supports an overall decrease in pacemaker risk by at least 50% with SAVR as compared to TAVR. Especially in younger patients of low to intermediate surgical risk, discussion of pacemaker risk is important in the selected aortic valve strategy. The long-term implications of a conventional transvenous device must be weighed, especially in younger, active individuals. The long-term infectious risk is also not trivial, given a longer theoretical dwell time in lower risk, younger patients. A higher longitudinal device infection risk also increases the risk of prosthetic valve endocarditis. Though progress has been made with decreasing overall TAVR thirty day mortality from 2011 (7.2%) to 2019 (2.5%), new pacemaker rate has remained stagnant at 10.8% (40). With a very low post-RAVR pacemaker incidence, RAVR offers a viable option to mitigate both pacemaker and long-term infectious risk.

Stroke risk

In the low-risk pivotal SAVR/TAVR trials, observed trends are higher for stroke in SAVR in shorter term follow-up, with attenuation between the two arms with longer-term follow-up. In the PARTNER 3 low-risk trial, stroke favored TAVR (1.2% *vs.* 3.1%) at one year, which narrowed at five years (5.8% *vs.* 6.4%, 95% CI: 0.51–1.48) (17). Three-year Evolut low-risk data demonstrated disabling stroke at 2.3% in TAVR and 3.4% in SAVR (P=0.19), with subsequent four-year data reversing the trend at 8.2% *vs.* 7.7% (P=0.69). Real-world STS-TVT registry analysis over ten years saw a decrease in stroke in TAVR from 2.75%, to 2.3% annually from 2011 to 2019 (40). Irrespective of a clinical trial context versus real-world observation, the consideration of stroke risk is critically important in the MDHT of low- to intermediate-risk patients.

Comparing RAVR with TAVR, the propensity-matched analysis demonstrated a higher stroke rate in TAVR compared with RAVR (4.9% *vs.* 0.7%) at one year, even with 38.9% of the TAVR arm undergoing transcatheter cerebral embolic protection (CEP) at the time of index procedure (36). Data surrounding routine CEP use is still controversial. The PROTECTED TAVR trial suggested no difference in overall incidence of stroke within 72 hours after TAVR, with a possible signal for benefit in disabling stroke in those randomized to CEP (41). Stroke reduction in TAVR continues to be a challenge with no consensus on routine CEP use to date. Based on initial data, prospective data, and the advantage of precise camera visualization to meticulously aspirate calcific debris, RAVR may be a strategy to mitigate stroke risk, particularly in younger patients with BAV and/or significant annular/LVOT calcium.

Anatomical considerations

Complex anatomy such as bicuspid aortic valve (BAV), high left ventricular outflow tract (LVOT) or annular calcific burden, and steep aortic root angles affecting TAVR coaxial alignment are important considerations in short- and long-term outcomes. BAV can affect up to almost 50% of younger patients undergoing SAVR. When comparing TAVR with SAVR in BAV, available data are predominantly registry-based and non-randomized. BAV has a significant calcific burden that may be asymmetric and circumferential with non-circular annuli and a high burden of calcium within the LVOT. Two registry-based propensity-matched analyses published in 2022 reported no significant difference between BAV and tricuspid anatomy patients treated with TAVR for both BEV and SEV platforms in the primary composite outcomes of all-cause mortality, stroke and cardiovascular re-hospitalization (42-47). Extensive raphe and/or subannular calcification were excluded. The sample sizes were small in each study, and not all baseline characteristics could be matched, such as STS PROM and annular sizing. Sievers type 0 anatomy consisted of only 10–14% of patients in each study—a variant challenging in TAVR due to lack of raphe and ellipsoid annuli. Ultimately, variance in BAV phenotype and morphology is likely not adequately represented in these nested registries due to exclusions. In one registry analysis of CT studies of BAV patients undergoing TAVR, two-year mortality was reported at 12.5%. Detailed multivariable analysis identified calcified raphe or excess leaflet calcification on CT as independent predictors of two-year mortality. The presence of both factors increased the two-year all-cause mortality to 25.7% (30). TAVR in BAV has been associated with higher rates of PVL, stroke and annular rupture (24,48). Moderate or severe LVOT calcification has been associated with higher risk of annular rupture, bailout valve-in-valve implantation and PVL. In addition, increased pacemaker risk after TAVR with high LVOT calcium volume as quantified by CT has been reported. Despite its technical feasibility in BAV, TAVR may not be the ideal upfront treatment strategy, particularly in younger patients who are more likely to have BAV. Therefore, RAVR may offer the ability to mitigate the risk of suboptimal results of TAVR in challenging anatomy via a minimally invasive surgical approach.

SVD

SVD in TAVR versus SAVR has become an important contemporary discussion with intermediate-term, low-risk trial data. Longer life expectancy in the low- to intermediate- risk patient warrants careful consideration of initial and potential future anticipated AV interventions. SVD in TAVR is thought to be due to prosthetic implant within native calcific annuli, causing potential turbulence at the aortic root/sinus of Valsalva, leading to increased shear stress. Suboptimal deployment characteristics, such as incomplete/asymmetric frame expansion and balloon dilation also may contribute. Subclinical leaflet thrombosis can be identified on CT as hypo-attenuated leaflet thickening (HALT). A meta-analysis of 22 studies with 11,567 patients reported a HALT rate of 15% after a median time of 140 days from TAVR (48). In the CT sub-study of PARTNER 3 of 408 patients who received CT at thirty days and one year, HALT was significantly higher in TAVR vs SAVR (13% *vs.* 5%, 95% CI: 1.11–6.32) at thirty days. This difference attenuated at one year to 28% *vs.* 20% (95% CI: 0.87–2.18), which no longer met statistical significance (49). The Evolut low-risk trial at one year showed a frequency of 30.9% in TAVR and 28.4% in SAVR (P=0.661). The data suggest that subclinical leaflet thrombosis may affect both bioprostheses similarly. Collectively, trial and registry data consistently report a higher numerical trend in TAVR.

While longer-term follow up is still required for SVD from low-risk clinical trial data, RAVR may serve the role of an initial aortic valve replacement strategy designed for durability without upfront sternotomy. Not only for the option of mechanical prostheses, but also for the advantage of optimal surgical implantation of a surgical bioprostheses with respect to coronary heights, an initial RAVR approach in certain patients offers the advantage of optimal conditions in the future if valve-in-valve TAVR is needed for SVD.

Concomitant procedures

RAVR allows for an array of concomitant procedures addressing other valvular pathology, septal defects and AF. As previously discussed, the first 212 multicenter RAVR cases report 10.8% (n=23) underwent aortic root enlargement. This offers the ability to optimize valve hemodynamics in anatomy concerning patient prosthesis mismatch. 16.5% underwent other concomitant surgical procedures: 3.4% (n=7) LAAO alone, 8.8% Cox Maze with LAAO (n=18), 3.9% PFO closure (n=8), 1.5% transaortic myectomy (n=3), 3.4% MVr (n=7) and 3.4% MVR (n=7). Especially in patients with AF, the ability to perform concomitant Cox-MAZE with LAA ligation may offer improved clinical outcomes. This was studied in a propensity-matched cohort study of Medicare beneficiaries undergoing SAVR with concomitant AF treatment versus TAVR and AF treatment in follow-up from 2018 to 2020 (50). AF treatment in SAVR (n=3,176) was defined as LAAO with or without surgical ablation. AF treatment in TAVR was defined as endovascular LAAO and/or AF catheter ablation at any time during the study period. But due to a relatively small size of TAVR + AF (only 4.5% of the total sample size), the focus of the analysis compared SAVR alone, SAVR + AF and TAVR alone. TAVR was associated with increased pacemaker rates and vascular complications. Longitudinal outcomes showed three year survival advantage of SAVR + AF compared with TAVR alone (HR 0.79, P=0.19), lower readmission for stroke (0.68, P<0.001), and lower composite of stroke and death (0.66, P<0.001).

In the TAVR space, the WATCH-TAVR trial (n=349) compared in a randomized fashion TAVR alone (n=172) with TAVR and percutaneous LAAO (n=177) (51). There was no difference in the primary composite endpoint of all-cause mortality, stroke, or major bleeding at two years. Though insightful, the WATCH-TAVR was small and more hypothesis-generating. Ultimately, the TAVR + LAAO approach needs to be studied prospectively compared with SAVR + AF. Extrapolating the available comparative SAVR + AF advantages to RAVR, RAVR offers the option of a durable rhythm and stroke management strategy of AF compared with TAVR. In addition, along with the ability to address pure aortic regurgitation, mitral/tricuspid pathology, septal defects, and optimizing valve hemodynamics with aortic root enlargement, if necessary, RAVR's versatility while maintaining a minimally invasive approach should continue to be a relevant discussion at appropriate centers for the management of AS.

Conclusions

In summary, RAVR is an important, safe, and effective option for the management of aortic valve disease at appropriate centers. Generational improvements in prosthetic design to increasing standardization of implant technique has led to improved overall safety and outcomes. This optimism must be tempered in a balanced approach, with a tailored, individualized approach to the patient with AS. In the longitudinal management of symptomatic severe AS, the first management strategy is critical to laying the foundation for future options if reintervention is needed. These considerations, as already reviewed, are imperative, especially in the younger patient of low to intermediate surgical risk with longer life expectancy. RAVR may have a key role in the initial management strategy of patients, with high calcific burden with/without BAV, need for concomitant AF or valvular/septal surgery, without the invasiveness of conventional SAVR. As increasing centers worldwide participate in consensus training requirements for RAVR, the learning curve and resource requirements may permit its more widespread adoption over time. A thorough MDHT should be the standard, and in appropriate centers, a "RAVR first" approach may be achieved safely and effectively to address aortic valve pathology via a minimally invasive non-sternal surgical approach with excellent clinical outcomes.

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