1.2 Aortic root enlargement during surgical aortic valve replacement

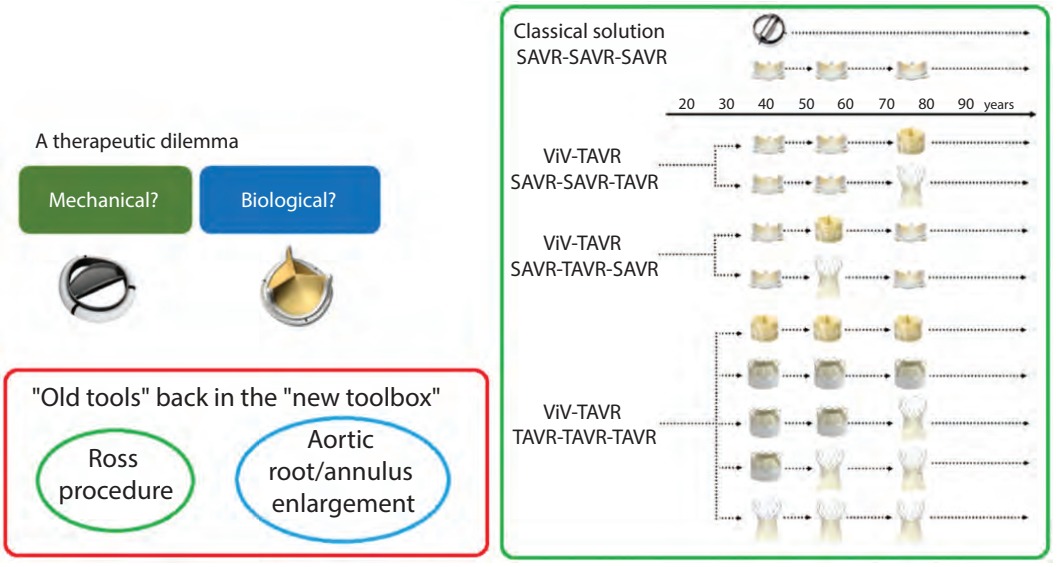
Chi Chi Do-Nguyen, Sarah T. Palmer, Gorav Ailawadi, Bo Yang

The introduction of transcatheter aortic valve replacement (TAVR) for patients who are at high risk for conventional surgical aortic valve replacement (SAVR) has changed the lifetime management of aortic valve disease. At present, the Edwards balloon-expandable bioprosthetic valves are available in sizes 20, 23, 26, and 29 mm with annular sizes from 18 mm to 27 mm and the Medtronic CoreValve/Evolut self-expanding bioprosthetic valves (Medtronic, Dublin, Italy) are available in sizes 23, 26, 29, and 34 with annular sizes from 18 mm to 29 mm.[1] Compared to medical management, TAVR has been found to be associated with improved 1- (30.7% TAVR *vs.* 50.7% medical) and 2-year mortality rates (43.4% TAVR *vs.* 68.0% medical) in patients with an STS Score <15%.[1] Compared to surgical management, TAVR was found to have similar 1- (24.3% TAVR *vs.* 26.8% SAVR) and 2-year mortality rates (33.9% TAVR *vs.* 35.0% SAVR) in patients at high risk for surgery.[1] With continued trials and promising results, TAVR has been approved for use in high-, intermediate-, and low-risk surgical patients. The ever-growing population and longer life expectancy require innovative strategies for the lifetime management of aortic valve disease throughout all phases of life (Figure 1.2.1).[2]

Prosthesis-patient mismatch

Although efforts are made to preserve the natural aortic valve, when possible, an aortic valve replacement (AVR), whether surgical or transcatheter, is warranted in most patients with aortic valve pathology. The goal of SAVR is to leave the patient with a prosthetic valve which has the same or larger inner diameter as the patient's native aortic annulus. However, if a relatively small prosthesis is implanted, the patient may be left with a small valve area and high residual transvalvular gradient, creating a new problem of prosthesis-patient mismatch (PPM). This phenomenon was first described in 1978 by Rahimtoola who pointed out that in patients with a small-normal aortic annulus, small prosthetic valves (bioprosthetic and mechanical valves) implanted without upsizing the valve sizes through aortic annular

FIGURE 1.2.1. Diagram illustrating possible solutions with surgical and transcatheter techniques for a lifetime management of aortic valve disease.

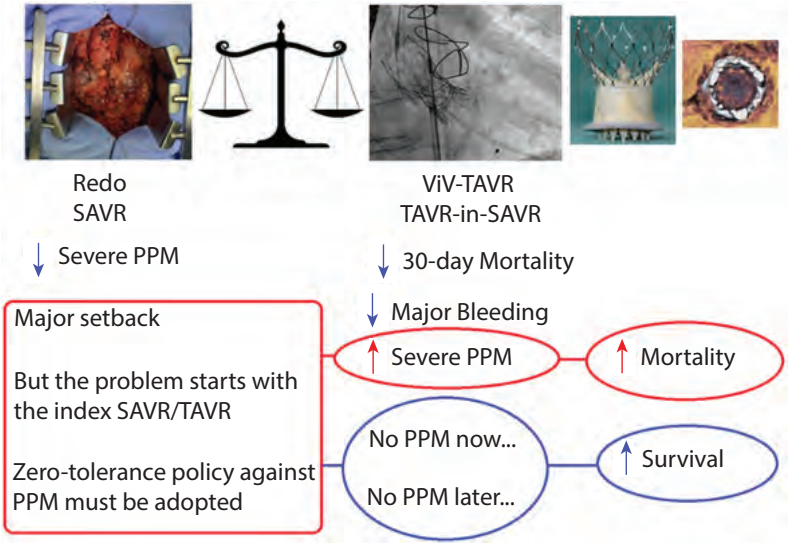


From: Sà *et al*.[2]
SAVR: surgical aortic valve replacement; TAVR: transcatheter aortic valve replacement; ViV: valve-in-valve.

enlargement result in PPM. This has remained a dilemma for surgeons when performing SAVR in patients with a normal aortic annulus (19-25 mm).

PPM is defined as the concept of having an effective prosthesis valve area (the opening of the cusps) smaller than the normal human valve area, and this has been shown to negatively impact postoperative survival, as the patient continues to have progression of left ventricular hypertrophy.[1, 3, 4] Therefore, the patient's body surface area (BSA), lifestyle, and age must be considered when choosing the appropriate aortic valve prosthesis. Specifically, patients with a larger BSA require a higher flow rate across the valve than a patient with a smaller BSA. Knowledge of the patient's BSA and the effective orifice area (EOA) of given sizes of a particular prosthetic valve will allow for preoperative determination of the minimum prosthetic size required to leave the patient with an appropriate EOA/BSA ratio, otherwise known as indexed EOA (EOAi).[4] It is generally accepted that the likelihood of PPM is minimized if the prosthesis provides the patient with an EOAi>0.85 cm^2/m^2. An EOAi of 0.65 to 0.85 cm^2/m^2 is considered moderate PPM, and <0.65 cm^2/m^2 is considered severe PPM. If the patient's Body Mass Index (BMI) is greater than 30 kg/m^2, an EOAi of 0.55 to 0.75 cm^2/m^2 is considered moderate

FIGURE 1.2.2. Diagram illustrating the importance of preventing PPM in the lifetime management of aortic valve disease.



From: Sà *et al.*[2]
PPM: prosthesis-patient mismatch; SAVR: surgical aortic valve replacement; TAVR: transcatheter aortic valve replacement; ViV: valve-in-valve.

PPM and <0.55 cm^2/m^2 is considered severe PPM.[5] This recommendation is derived from the fact that an indexed AVA of 0.6 cm^2/m^2 is considered severe aortic stenosis. The use of this guideline is helpful as it places the consideration of valve size in the context of the patient's hemodynamic needs rather than in absolute terms. Also, it is important to be cognizant that all echocardiographic gradients are measured when patients are at rest, which underestimates the PPM when patients are active. When the aortic valve area is reduced to $<35\%$ of normal, the gradient rises drastically.[4] Therefore, to avoid any significant increase in gradient across the aortic valve, the valve area must be above 2 cm^2, assuming that the normal valve area is 3 cm^2. Patients who present at a younger age may need multiple valve interventions across their lifespan, so a lifetime strategy must be planned at the initial intervention.

Several studies using the EOAi have shown negative impacts of PPM on clinical outcomes. It is associated with less improvement in symptoms (*i.e.*, functional New York Heart Association [NYHA] class), less regression of the left ventricular mass, as well as worse early mortality (in particular, when a low left ventricular ejection fraction is concomitantly present) and adverse events during long-term follow-up.[6] The impact of

PPM on in-hospital mortality after AVR may be particularly important, as the left ventricle is more vulnerable to increased stress and may be more sensitive to the increased afterload associated with PPM in the postoperative course. In a study of 1,266 patients who underwent SAVR, Blais *et al.* found that the relative risk of mortality was increased 2.1-fold (CI: 1.2-3.7) in patients with moderate PPM and 11.4-fold (CI: 4.4-29.5) in those with severe PPM.[7] Further, the negative impact of severe PPM on all-cause mortality for patients with a small annular size is observed not only in SAVR cohorts, but also TAVR cohorts (Figure 1.2.2).[2,4]

Size issue

One factor confounding the interpretation of these data is the fact that the sizing of bioprosthetic valves is inconsistent from one manufacturer to the others. Depending on the manufacturer, a size 19 mm valve may vary in EOA from 1.0 to 1.3 cm^2. Moreover, the inner diameter of a bioprosthetic valve measures 5 mm to 7 mm smaller than the advertised valve label size, which usually correlates with the outer diameter.[1,8] By default, this renders initial implantation of a 19 mm, 21 mm, and perhaps even a 23 mm valve too small in relation to the average patient's native LVOT and aortic annulus size.

Therefore, the size of the index valve implant is of critical importance, especially considering the prior and current landscape of SAVR in the U.S. In well-known clinical trials, such as the Placement of Aortic Transcatheter Valves (PARTNER), CoreValve US Pivotal Trial, Nordic Aortic Valve Intervention (NOTION), Evolut R Low Risk, and other large series of SAVR, the most used surgical valve sizes were 21 mm to 23 mm, comprising 60-73% of implanted sizes. This is more important in the era of TAVR and the growing population of patients undergoing valve-in-valve procedures. Small SAVR valve sizes (19-23 mm) were associated with higher gradients and greater incidence of severe PPM after valve-in-valve TAVR in a prior surgical valve.[4] Given these considerations, it is crucial to place a large enough valve at the initial SAVR operation to account for optimal lifetime management of aortic valve disease.

By definition, a stented prosthetic valve will have the sewing ring and struts, which occupy space within the aortic annulus. To obtain a larger effective orifice area, an aortic annular/root enlargement (AAE or ARE) may be warranted at the initial encounter before the placement of a stented prosthetic valve. The goal of aortic annular enlargement (AAE) is to enlarge the anatomic or surgical aortic annulus which is part of the aortic root. The purpose of aortic root

enlargement (ARE) is to enlarge the aortic root and create larger sinuses, which often is just a non-coronary sinus enlargement without enlarging the surgical aortic annulus. Thus, AAE but not ARE allows the placement of a larger surgical prosthesis. According to the STS National Cardiac Surgery Database, from 2008 to 2016, only 2.9% of SAVR with or without concomitant coronary artery bypass grafting underwent AAE. Even in the more recent trials of low- or intermediate-risk patients, only 4.6% of SAVR patients in the PARTNER 3 trial, and 1.6% of patients in both the Evolut low-risk and the Surgical Replacement and Transcatheter Aortic Valve Implantation (SURTAVI) trials had AAE. The low rates of AAE may be explained by the perceived increase in complexity and complications of the procedure.

Several studies have shown that performing AAE at the time of aortic valve replacement significantly increases postoperative complications, such as acute kidney injury, prolonged ventilation, and even operative mortality. However, the validity of the comparisons between patients receiving and not receiving AAE in these observational studies has been debated. Based on the methodology in all three studies, the AVR group and AVR+AAE group are not comparable.[9] The AVR groups have been comprised of patients with a large annulus (apples) without the need for AAE, while the AVR+AAE groups have included patients with a small aortic annulus (oranges) requiring an AAE procedure. That is why the AVR groups have received significantly larger prostheses compared the AVR+AAE groups in all three studies, despite the AVR+AAE groups having undergone an annular enlargement procedure. The patient's native aortic annulus size in the AVR+AAE groups might even be at least 1-2 valve sizes smaller than the implanted valve size prior to the annular enlargement. Therefore, it is not surprising that the AVR+AAE groups have worse peri-operative outcomes. After propensity score matching to adjust for the native annular size (19-23 mm) as well as other comorbidities, our group found that in the AVR+AAE group, the median size of the prosthesis was two valve sizes larger. Perioperative outcomes were similar between groups, but the AVR+AAE group had significantly better 5-year survival with a hazard ratio of 0.47.[10]

A comment can be made regarding an alternative approach to enlarging the native annulus/root, which is root replacement altogether. Implantation of stentless bioprosthetic valves was initially reported in 1990. Because these stentless roots lack the rigid sewing band and struts, they offer an inherently larger EOA. However, stentless bioprosthetic valves are a greater technique challenge

to treat with future valve-in-valve TAVR. While some controversy exists in the literature, it is generally accepted that the hemodynamic performance of stentless bioprosthetic valves is better than that of stented valves. However, after adjusted valve size, surgeon, and other comorbidities, patients treated with stented and stentless had similar long-term survival.[11]

Aortic annular root enlargement techniques

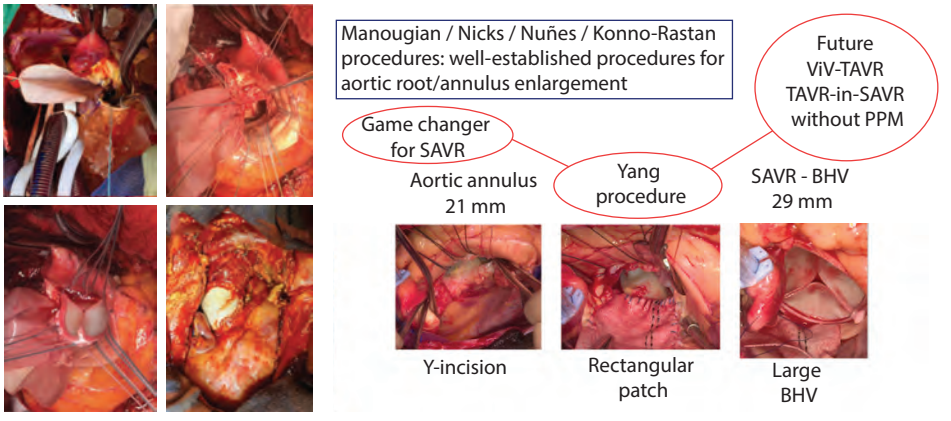
Several techniques have been cited over the years, with the Nicks and Manouguian techniques being the most popular amongst current cardiac surgeons, both being posterior approaches to enlarging the aortic root. Nicks and colleagues first described a posterior approach to aortic annular enlargement in 1970.[12] The technique involves an aortotomy in the midline of the noncoronary cusp to the origin of the mitral valve. A similar posterior approach was described by Manouguian in 1979, in which the aortotomy is extended by a vertical incision through the left- and non-commissure to the origin of the mitral valve.[13, 14] Both techniques generally increase aortic annulus size by one to two valve sizes. Amongst one of the most popular techniques used to date, these techniques are critiqued for their risk of MR, which has an occurrence rate of up to 14%.[15]

Utilizing a more extensive and complex anterior approach, the Konno-Rastan aortoventriculoplasty originally described by Konno in 1975 aimed to relieve subvalvular, valvar, and supravalvular stenosis.[16, 17] To perform this technique, an anterior aortotomy is created in the subaortic region through the right coronary sinus medial to the right coronary ostium allowing enough room to prevent injury to either coronary artery. This technique can result in an enlargement of the aortic annulus by 2-3 valve sizes through the enlargement of both the RVOT and left ventricular outflow tract (LVOT). A benefit of the Konno-Rastan aortoventriculoplasty is the ease of placing a prosthetic valve and the lack of need to mobilize the coronary arteries.[18] However, it carries the risk of injury to the septal arteries (especially the first septal branch of the left anterior descending coronary artery), conduction system, and pulmonary valve when done without precision.[1] Furthermore, many patients develop RV dysfunction in the initial postoperative period, making appropriate patient selection crucial.[18]

A more novel technique introduced in early 2020 by our group can increase the aortic annulus size by up to three to five valve sizes (Figure 1.2.3).[2, 8, 19-21] This technique is performed via a complete

or partial transverse aortotomy spanning from 2 cm above the sinotubular junction and stopped above the left-non commissure post. The incision is extended as an inverted "Y" underneath the aortic annulus of the left and non-coronary sinus into the left and right fibrous trigone underneath their respective nadir ("Y incision"). The key details in this technique are to place the sutures on the anatomic (or surgical) aortic annulus to secure the prosthetic valve like a normal AVR, not the virtual basal ring, to tie the nadir sutures first to prevent paravalvular leakage, and to ensure that a portion of the patch lay beneath the prosthetic valve to appropriately enlarge the aorto-mitral curtain and aortic root without violating the structures around the aortic root, including mitral valve, nor incurring the risk of MR. This technique differs from earlier renditions due to the enlargement of the surgical aortic annulus and root instead of the basal ring and LVOT.[22] Inside the aortic root, the crown-like structure through which the cusps of the aortic valve attach to the aortic wall is defined as the anatomic (or surgical) aortic annulus. In contrast, the virtual basal ring of the aortic root is the ring connecting the three nadirs of the three cusps, which can be measured by echocardiogram and computed tomography aortogram and is also called an aortic annulus. For an AVR, we place the sutures on the anatomic (or surgical) aortic annulus to secure the prosthetic valve, not the virtual basal ring. Similarly, the

FIGURE 1.2.3. Illustration of the ability for surgical techniques to lend way to future transcatheter techniques for a lifetime management of aortic valve disease.



From: Sà *et al.*[2]

PPM: prosthesis-patient mismatch; SAVR: surgical aortic valve replacement; TAVR: transcatheter aortic valve replacement; ViV: valve-in-valve.

goal of AAE is to enlarge the anatomic aortic annulus and the root to accommodate a larger valve inside the aortic root, with the inner diameter of the prosthetic valve matching or exceeding the diameter of the basal ring.[22] A "roof" addition to the rectangular-shaped patch may be incorporated into the aortotomy closure to enlarge the proximal ascending aorta to adequately accommodate the root enlargement and future valve-in-valve TAVR.[19, 23-24] This can be especially beneficial in patients with an ascending aorta <30 mm in diameter.

The Y-incision enlargement technique is in its early years; however, outcomes to date have proved to be promising.[8] In 50 consecutive patients that underwent SAVR with the Y-incision aortic annulus enlargement, there were no major postoperative complications. Only one patient had a stroke exacerbation and nine developed atrial fibrillation.[8] In the first 113 consecutive cases, complications included 1 stroke, 2 complete heart blocks, 1 aortic valve endocarditis, and Gerbode fistula, and 1 mortality in a patient who had an AVR with AAE, mitral valve replacement, coronary artery bypass, and MAZE procedure who died from mesenteric ischemia. The Y-incision enlargement technique avoids the complications of prior techniques including MR, injury to the septal arteries, conduction system, pulmonary valve, and RV dysfunction. Meanwhile, the technique can increase the aortic annulus size by up to 3-5 valve sizes, the most to date. We compared TAVR to SAVR with Y-incision AAE and found after propensity score match, the 2-year survival and left ventricular mass index regression was significantly better in the SAVR+Y-incision group. The long-term survival of the patients and the durability of the bovine prosthetic valve could be better in patients treated with SAVR with Y-incision AAE, but we need long-term data to prove those speculations.

Significance

The ever-growing population and longer life expectancy require innovative strategies for the lifetime management of aortic valve disease throughout all phases of life.[2] With the implementation of TAVR in low-risk patients, the mean implantation age is now below 75 years, rendering life expectancy beyond the durability expectations of prostheses.[25] Patients who present at a younger age may need multiple valve interventions across their lifespan, so a lifetime strategy must be planned at the initial intervention. There is not a clear answer to a SAVR- *vs.* TAVR-first approach for these young patients. Although the technology for transcatheter leaflet laceration