Aortic valve neo-cuspidation using the Ozaki technique for acquired and congenital disease: where does this procedure currently stand?

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Abstract

The surgical treatment options for pediatric aortic valve disease are limited. The Ozaki procedure, which involves templated creation of new aortic valve leaflets, has proved to be a promising surgical technique. This review aims at elaborating the indications, technical intricacies, and outcomes of the aortic valve neo-cuspidization procedure (Ozaki procedure) in the pediatric population.

Keywords Ozaki procedure · Aortic valve neo-cuspidization · Aortic valve repair/reconstruction · AVNeo

Introduction

Options for aortic valve disease have increased in the last decade including repair, reconstructive, and replacement options. A variety of creative techniques including leaflet extensions, neo-leaflet creation, resuspension or plication of prolapsing leaflets, and commissuroplasty to repair valves have been technically mastered [1–3]. In adults, the advent of transcatheter aortic valve implantation now allows treatment of degenerative aortic stenosis in the oldest and the highest risk patients [4]. However, surgical treatment options for pediatric patients with complex congenital aortic valve disease remain limited.

In 2011, Professor Shigeyuki Ozaki initially described the aortic valve neo-cuspidization procedure (AVNeo) in a series of adult patients [5]. It received Food and Drug administration approval in the USA in 2014 and is commercially available through the Japanese Organization for Medical Device Development (JOMDD, Tokyo, Japan) company [6]. The AVNeo system is based on single or multi-use sizing templates and measurements are based on the aortic valve coaptation points and commissures being in the same plane with the ratio of distance between two commissures and free edge length being similar. The original sizers and template were

manufactured in sizes 17 to 31 mm and the smaller pediatric sizes (13, 15 mm) were introduced in 2015. We began AVNeo at Boston Children's Hospital for pediatric patients with congenital heart disease in 2015.

Methods

Operative candidates

Patients of all ages (adults and children) and those with acquired and congenital aortic valve disease including those with prior mechanical or bioprosthetic valves should be considered for an AVNeo procedure. Younger patients with hypoplastic annuli are candidates for aortic root enlargement procedures such as a Konno, Nicks, and/or Manouagian prior to AVNeo reconstruction. The technique can also be used in the adult congenital population with cono-truncal disease including truncus and transposition of the great arteries. It is also possible to do an AVNeo reconstruction followed by a valve sparing root type replacement procedure (aka: David-Ozaki or Yacoub-Ozaki procedure) or a bio-Bentall with the AVNeo valve reconstructed within a tube graft prior to implant (Fig. 1).

Pre-operative imaging

The aortic annulus, root, and sino-tubular junction measurements can be made on pre-operative CT scan or echocardiography

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Fig. 1 Bio-Bentall with the AVNeo valve reconstructed on the back table before cardiopulmonary bypass. Can be constructed within a Gelweave Valsalva graft or standard Hemashield Dacron tube graft. Generally, the AVNeo template size corresponds to one size more than the graft (i.e., 20-mm Dacron tube = 21-mm size leaflets)

Standard transthoracic echocardiographic imaging will suffice in consideration for the AVNeo procedure while pre- and intra-operative transesophageal echocardiographic imaging can better define the annular dimensions. Accurate measurement of annulus can alert for the need of an annular enlargement procedure. Additionally, subaortic membranes, significant septal hypertrophy, and ascending aortic dilation should be considered. Three-dimensional echocardiography can provide useful insights into the mechanisms of valve failure and help determine the need for a complete three-leaflet vs. single-leaflet reconstruction. Computerized tomographic (CT) imaging can also be used to determine more definitive annular and ascending aortic measurements which can allow for pre-cutting of the leaflets in order to save ischemic cross-clamp time.

AVNeo reconstruction in adult and pediatric patients

The standard technique can be modified in a number of ways to suit indications for those who had a prior aortic valve replacement, pediatric patients and those with congenital aortic valve disease including unicuspid, bicuspid, and quadricuspid valves. The predominant pathology encountered in the older adult population is acquired calcific aortic stenosis but frequently associated with bicuspid valves. The pathology of young pediatric patients is primarily congenital aortic valve stenosis with resultant regurgitation following balloon aortic

valvuloplasty. Regardless of the population, complete excision of existing leaflets and fibrous calcification or previously replaced valve allows great flexibility in using the AVNeo procedure which is not restrained by native commissures, cuspal number, size, or position.

Modified surgical techniques for congenital patients

The surgical technique has been previously described for adult patients by Ozaki et al. [5]. Briefly, a full, upper partial sternotomy or mini-sternotomy is utilized. Preferably a thinner portion of autologous pericardium is harvested and affixed with the rough surface up to a stainless steel plate with tension applied to prevent wrinkling (Fig. 2). Fibrous and adipose tissue is aggressively removed. The affixed pericardium is immersed in 0.6% glutaraldehyde for 2–10 min and then rinsed for 6 min, 3 times for a total of 18 min. Previously we treated pericardium for 10 min; however, due to concerns for calcification since April 2017, we now treat the pericardium for 2 min. Normo- to mildly hypothermic cardiopulmonary bypass is established, the aorta is cross-clamped and cardioplegia administered.

Valve exposure

Several options should be considered for optimal aortic valve exposure. In larger adult patients, a simple partial anterior aortotomy, 5–8 mm above the top of the commissures, is acceptable but complete transection is most optimal. For smaller patients with more complex disease, opening the non-coronary sinus will provide the most optimal exposure. Importantly, when closing this sinus, it is essential to make sure that the sinus dimension allots the same distance between the commissures as the annulus to avoid shortening and buckling (Fig. 3a) or lengthening and stretching (Fig. 3b) the neo-leaflet.

Annular preparation and sizing

The leaflets are excised completely using sharp dissection and annulus debrided. All existing cusps, associated calcium and fibrous attachments, are excised. If a previous prosthetic valve is in situ, it is completely excised with all the associated calcium, pledgets, and old suture material. Accurate measurement of the inter-commissural distance is done using the sizing device (JOMDD, Tokyo, Japan). A similar device has also been introduced by Mourad [7]. For tri-leaflet valves, the sizer is used to measure the commissures by aligning the edge of the sizer between two adjacent commissures and repeating for all three commissures (Fig. 4). Consideration is given to the dynamic annulus which will be slightly larger during diastole. Thus, it is preferable to upsize rather than downsize the leaflet size. After determining the size of each leaflet, the

Fig. 2 a Stainless steel plate with rough side of autologous pericardium affixed under tension and fixed in 0.6% glutaraldehyde for 2 min and rinsed in saline for 6 min for 3 times. Overlying AVNeo valve leaflet template with sizes between 13 and 35 mm. Inset—23 mm valve leaflet template. Note that guiding points for suturing and commissure reinforcement are pre-marked. The double dot represents the mark for taking the deep bite as described in methods.

b The first suture starts at the center (•) and each bite through the leaflet should be at 5-mm intervals, and at 1-mm intervals on the annulus. At the point where the remaining portions for the leaflet become slightly longer or close to the remaining length of the annulus, the bites should become equidistant, 1:1. The double dot represents the second to last and deep bite through the aortic wall

center of each leaflet is marked on the annulus. As is often encountered in the pediatric population, three uniform commissures might not exist in which case new commissural positions are selected and marked after considering coronary origins. Generally, the reference starting point for commissural creation is based on the coronary origin and is frequently the inter-coronary commissure.

Annular enlargement

In patients with small annuli, root enlargement techniques are considered. When enlarging the annulus, the patients' age and weight should be taken into account and is often upsized to a Z-score of +2. A Konno-type incision towards the right ventricular outflow can be used for anterior enlargement while a Nicks or Manouagian enlargement towards the mitral annulus can be done posteriorly (Fig. 5). Frequently, we will combine anterior and posterior enlargements to provide a more symmetrical enlargement. In the smallest patients, annular enlargements can be considered using the three commissures. Once completed, the sizers are used as above to outline the new annulus.

Leaflet design

The leaflets are designed using the template (Fig. 2a). The pericardium closest to the diaphragm is thickest and used to make a larger leaflet. Additionally, bovine pericardium can be used. Using the template, after marking the outer periphery, draw the “dots” on the 5-mm extension wing, draw a longer line in the center of leaflet, and draw other “dots” in accordance with the template (Fig. 2a—inset). Rinse the leaflets in saline until use.

Leaflet suturing

When preparing to suture leaflets, the smooth surface should face the left ventricle. The 4-0 Prolene (5-0 in smaller patients) on a TF needle should follow the path: smooth surface of leaflet → bottom of annulus → top of annulus. First, pass the needle through both the dot in the center of the leaflet and corresponding dot in the center of annulus. The suture is tied with two knots. Each bite through the leaflet should be at 5-mm intervals, and at 1-mm intervals on the annulus (Fig. 2b). At the point where the remaining portions for the leaflet

Fig. 3 The inter-commissural distance represented by the blue line is optimal for the leaflet size. Note three equal leaflets and equal inter-commissural distances. **a** Represents a shorter distance between the right/non and non/left commissures making the non-coronary sinus too small. This is corrected by enlarging the sinus with a pericardial patch. **b**

Represents a longer distance between the right/non and non/left commissures making the non-coronary sinus too large. This is corrected by resecting a segment of the sinus. LCA, left coronary artery; RCA, right coronary artery

become slightly longer or close to the remaining length of the annulus, the bites should become equidistant, 1:1.

Commissure creation

A deep bite should be taken at the second to last or double dot. The final suture on the cusp is generally 5 mm from the edge. After the needle passes through the last dot, it should pass through the aortic wall 2 mm below the uppermost point of the commissure. Construct the commissure using 4-0 Prolene (5-0 for smaller patients) on an RB-1 needle. The following four points must be penetrated—one midpoint between the

free edge and the previous stitch (approx. 2.5 mm from the edge) at a height near the native commissure, and also the sutured point at the top corner of the wing extension. Then the aortic wall must be penetrated with 4 sutures facing outside of the aortic wall. The distance between the two lower 2 penetration points for the pledgets is narrow, while the distance between the 2 higher penetration holes is wider (Fig. 6a). It is important to make sure that the wings are securely attached to the aortic wall before knotting. This is completed three times for each leaflet and commissure. The wings are then affixed with a mattress suture and a figure-of-eight suture fixes the commissure to the aortic wall.

Fig. 4 The AVNeo sizer is used to measure and mark the commissures by aligning the edge of the sizer between two adjacent commissures. **a** Typically, the inter-coronary commissure is used as the reference commissure placing the coronary ostia in the central portion of the leaflets. **b** The sizer is then rotated and repeated for all three commissures. LCA, left coronary artery; RCA, right coronary artery

Fig. 5 Annular enlargement techniques. **a** Konno-type anterior annular enlargement. A pericardial patch is then used to reconstruct the annulus and sinus. **b** Anterior and posterior annular enlargements and

augmentation with pericardium. **c** Completed AVNeo procedure after annular enlargement. LCA, left coronary artery; RCA, right coronary artery

Sinus and sino-tubular junction reconstruction

Due to the dynamic nature of the entire aortic root complex including annulus, sinus and sino-tubular junction, it is essential to preserve symmetry both above and below the neo-annulus. Consequently, close attention is given to the dimensions of the aortic sinuses and sino-tubular junction and they are modified as needed. Inter-commissural distance at the level of the sino-tubular junction is a critically important distance as these areas cannot be under- or over-sized as leaflet function will be altered. Frequently the non-coronary sinus requires enlargement (Figs. 3 and 6b).

Concomitant procedures

Concomitant procedures along with AVNeo reconstruction are often required including ascending aortic reduction, arch reconstruction, mitral/tricuspid/pulmonary valve repairs and replacements, excision of subaortic membrane, biventricular repair, and right ventricle to pulmonary artery conduit change.

Post-operative management

Early post-operative management consists primarily of blood pressure control with a goal of early extubation.

Anticoagulation

Due to limited reports of patients having embolic complications following aortic valve reconstruction, in our early experience, we treated with aspirin only for 6 months. However, it was recognized that subclinical leaflet thrombosis occurred frequently following transcatheter implantation and bioprosthetic aortic valve replacement resulting in increased neurologic events which reduced leaflet motion on bioprosthetic aortic valves and the condition resolved with therapeutic anticoagulation [8]. Anticoagulation with both aspirin and warfarin, but not dual antiplatelet therapy, was effective in prevention or treatment of subclinical leaflet thrombosis [9]. In our series, 83% of patients having decreased leaflet mobility were on aspirin only. Based on these findings, we began to use dual therapy with aspirin and warfarin with a goal

Fig. 6 a Following a deep bite taken at the second to last or double dot on the pericardium, the needle is passed through the last dot and aortic wall. A second stitch is then taken and passed through each leaflet and aortic wall and passed through pledgets. **b** Completed reconstruction including augmentation of the non-coronary sinus to equalize all three inter-commissural distances

International Normalized Ratio (INR) of 1.5–2.5 for 3 months. Further investigation is warranted to determine an optimal anticoagulation regimen.

Results

Outcomes of the AVNeo technique in adults—Ozaki's experience

Professor Ozaki from Tokyo, Japan, has the world's largest experience with the AVNeo reconstruction procedure in adults. In 2011, they reported their initial experience of 88 patients with a mean age of 70.6 years with 65 patients having aortic stenosis. At 3 years of follow-up, freedom from reoperation was 100% [5]. Subsequently, in 2012, they reported their experience with 9 patients having unicuspid aortic valves with a mean follow-up of 1.5 years. They emphasized the importance of tricuspidization and that there were no reoperations during the follow-up period [10]. In 2014, they described their experience in 102 patients having bicuspid aortic valves with a mean age was 63.7 years with 2-year follow-up. Thirty-four patients also had concomitant hemi-arch replacement with 99% freedom from reoperation at 5 years [11]. In 2014, they described their experience on 108 patients less than 60 years of age with a mean age of 47.8 years. Freedom from reoperation was 98.9% at 6.3-year follow-up [12]. In 2018, they reported their overall extended experience with 850 patients using autologous pericardium [13]. Mean patient age was 71 years, mean annulus diameter was 20.9 mm, and aortic stenosis was the predominate diagnosis in 534 patients. Mean follow-up was 53.7 months and the longest follow-up was 118 months. There were 15 reoperations with a cumulative incidence of reoperation was 4.2% and development of moderate or greater aortic regurgitation was 7.3% [13].

Other AVNeo outcomes in adult patients

Other centers are also gradually accumulating and reporting their experience with AVNeo in the adult population. Reuthebuch et al. from Switzerland reported their experience with in 30 patients with a mean age of 66 years in 2018. Follow-up was limited (3 months), but there were no reoperations [14]. In 2018, Nguyen et al. from Vietnam also reported their minimally invasive experience in 9 patients with a mean age of 47.4 years with rheumatic aortic valve disease [15]. The procedure was performed through a mini-sternotomy and the pericardium was harvested using thoracoscopic guidance with no patient requiring conversion to full sternotomy. Rossekin from Russia has performed over 500 AVNeo procedures in adult patients [16]. Additionally, there are a number of other unreported centers from the USA, Europe, Asia, and South America performing AVNeo.

Boston Children's hospital experience in pediatric patients with with AVNeo

To date, there are few reports on pediatric patients with congenital aortic valve disease undergoing AVNeo. The Boston Children's Hospital experience with three-leaflet AVNeo reconstruction began in 2014. We recently reported our experience on 57 patients with a median age of 12.4 years [17]. Twenty-four patients had aortic regurgitation (AR), 6 had aortic stenosis (AS), and 27 patients had mixed AS/AR. Four patients had truncus arteriosus. Thirty-four patients had prior aortic valve repairs and 5 had replacements. Autologous, Photofix®, and CardioCel® bovine pericardium were used in 20, 35, and 2 patients. Eight patients underwent aortic root enlargements and 20 had non-coronary sinus enlargements. There were no hospital mortalities or early conversions to valve replacement. There were no differences in outcomes based on operative indication. At median follow-up of 8.1 months, 96% and 91% of patients had less than moderate regurgitation and stenosis, respectively [17]. More recently, we have identified 51 patients with a small aortic annulus (≤ 19 mm), with a median age 7.7 years, 20.6 kg that underwent AVNeo. Median native annular dimension was 16.5 mm and annular and/or sinus enlargements were completed in 22 patients with a median increase in Z-scores to 0.57. At mean follow-up of 10.5 months, 86% and 90% of patients had < moderate AR and AS, respectively.

Other AVNeo outcomes in pediatric patients

In 2015, Mazzitelli et al. reported their experience with 3 pediatric AVNeo procedures in patients 5, 11, and 15 years of age. Tissue-engineered bovine pericardium (Cardiocel®) was used to create cusps and there were no reoperations at early follow-up [18].

Extended indications

The AVneo technique has been uniquely adapted for other indications in the aortic and pulmonary positions. In 2015 at Children's Hospital Boston, we also began using the AVNeo sizers and template to construct one or two aortic valve leaflets, thus using one or two of the native leaflets (Fig. 7). We have performed 33 single aortic valve leaflet replacements in pediatric patients with a median age of 9.3 years and weight of 29 kg. The mean annular dimension was 20.1 mm and most commonly used leaflet size was 19 mm. At 1 year, freedom from $\geq$ moderate AS was 100% and $\geq$ moderate AR was 92%. At a median follow-up of 11 months, one patient having had a leaflet constructed with Cardiocel® required reoperation.

Several centers have reported creating a neo-pulmonary valve using the AVNeo technique (PulmNeo) directly in the native pulmonary annulus or within a conduit. We created

Fig. 7 Bicuspid aortic valve is converted into a competent tricuspid valve. A new aortic valve leaflet is constructed using the AVNeo sizer while retaining two native leaflets. The red dashed line represents the plane where the unicuspid/bicuspid is sharply taken down off the aortic wall. Inset—Completed single-leaflet AVNeo reconstruction. LCA, left coronary artery; RCA, right coronary artery

AVNeo and PulmNeo (Fig. 8) valves in a 16-month-old patient with Alagille syndrome and congenital aortic stenosis who had undergone neonatal aortic valve balloon dilation, followed by surgical bilateral branch pulmonary artery plasty and pulmonary valvectomy and who had severe aortic and pulmonary insufficiency and a short main pulmonary artery. The PulmNeo was constructed with 15-mm sizers and template using Cardiocel. At 1-year follow-up, there was no pulmonary stenosis or regurgitation.

Fig. 8 Creation of a neo-pulmonary valve using AVNeo technique. Inset—the use of the AVNeo sizer to measure for three equal leaflets. A transannular patch of pericardium is used across the right ventricular outflow tract and annulus and to cover the anterior sinus

Discussion

AVNeo allows natural aortic root expansion with maximal effective orifice preservation in systole [19, 20] and has been applied to a wide spectrum of aortic valve disease in adult patients [5, 12, 13]. While longer-term results in adults are promising, results in younger patients with congenital aortic valve disease remain less clear. We began AVNeo in 2015 in pediatric patients and have reported acceptable hemodynamics with no significant AR, low mean gradients, and annular growth, but continued consideration must be given to ongoing alternatives and limitations.

The advent of the Ross operation in 1967 was thought to be the ultimate solution for aortic valve replacement [21]. However, long-term outcomes of the Ross operation have become evident and new problems have emerged in younger patients. In 2007, Pasquali et al. reported outcomes on 74 patients undergoing Ross operation after a median follow-up of 4.7 years [22]. They demonstrated progressive neo-aortic regurgitation with an increase in the neo-aortic root size out of proportion to somatic growth. More recently, Sharabiani et al. demonstrated an increased overall cumulative risk with the Ross operation with a decrease in the patient age [23]. In addition, the Ross procedure converts a single valve disease to a double valve disease and reinterventions on the right ventricular outflow tract are inevitable.

Mechanical or bioprosthetic valve replacements remain less attractive options in the pediatric population but are sometimes unavoidable. Recently, a systematic review and meta-analysis by Etnel et al. reported in 2016 showed that all options for aortic valve replacement were suboptimal in the pediatric population [24]. In our own experience with mechanical valve replacement in children, freedom from aortic valve reoperation was 78.4% at 10 years [25]. In addition, younger age was an independent predictor of reoperation and valve sizes of 16 or 17 had a higher risk of reoperation. Chronic anticoagulation also remains challenging in younger patients.

Our experience with untreated bioprosthetic valves for children has been problematic with life-threatening aortic stenosis developing within 6 months [26].

“Repair” and “reconstruction” have been used interchangeably when describing a variety of aortic valve techniques [27–29]. Surgical principles include intervention on the aortic root and annulus or intervention on the aortic valve cusps such as plication, resuspension, leaflet thinning, and/or leaflet extensions. In pediatric patients with congenital aortic valve disease, valve pathology is different and needs further modification of repair strategies [1]. Utilizing historical strategies of surgical valvuloplasty for pediatric patients with AR, Bacha et al. demonstrated that freedom from aortic valve replacement was only 54% at 7.5 years [2]. Similarly, Polimenakos et al. reported that 78 patients less than 10 years of age treated with aortic leaflet cusp extensions had only a 55% 10-year freedom from aortic valve replacement [30].

In 1995, Duran et al. described a templated system of cusp extensions made of autologous pericardium which was labeled “replacement” [31]. The leaflets were not completely excised but left the partly excised leaflets uniformly to provide a suturing margin. Autologous glutaraldehyde-treated pericardium was used with a plastic mold to create leaflet extensions. Over 5 years, 49 patients were studied out of which 3 required reoperations: for infective endocarditis in two; and tear of one commissure 8 months after surgery in another [31].

Growth potential

Since the Ozaki technique does not fix the aortic annulus, the neo-aortic annulus grows with time. A generous coaptation height should allow to retain a satisfactory coaptation surface as the annulus grows and the coaptation height reduces [32]. In our experience, we have been able to demonstrate consistent annular growth [17].

Impact of material

The ideal material for aortic valve neo-cuspidization is still unclear. Traditionally, glutaraldehyde-treated autologous pericardium has been used for aortic valve repair and thus its use for AVNeo reconstruction. In Ozaki’s experience, autologous pericardium was initially used [13]. Being autologous, pericardium should be less antigenic; however, calcification remains the Achilles’ heel following glutaraldehyde treatment and particularly in pediatric patients [33]. Myers et al. reported their experience with 78 patients at a mean age of 12.3 years undergoing rheumatic aortic valve repair with cusp extensions. After a median follow-up of 10.6 years, fresh autologous and Photofix® pericardium trended towards better durability than glutaraldehyde-fixed bovine pericardium [34].

Photofix® is a biocompatible commercially available bovine pericardium with fixation using photo-oxidation without the use

of glutaraldehyde. Photofix® is relatively resistant to calcification and does not elicit a significant inflammatory response [35]. Early in our pediatric AVNeo experience, autologous pericardium and Photofix® have performed similarly with few failures. Failed Photofix® leaflets exhibited little calcification but appeared to have pulled from the intact suture line while the failed autologous glutaraldehyde leaflets showed significant calcification [17]. Photofix was previously used in a stented bioprosthetic valve where some patients had leaflet dehiscence at the leaflet-stent interface at a mean of 18 months [36]. Thus, continued follow-up will be important in AVNeo leaflets created with Photofix®. CardioCel® is a variant of commercially available glutaraldehyde-treated bovine pericardium. It is fixed using a novel tissue engineering technique ADAPT, followed by low concentration glutaraldehyde crosslinking [37]. In our early experience and others with CardioCel®, calcification occurs early and is of significant concern [38]. The Matrix® patch is a thinly sliced equine untreated pericardial patch with which several European centers report acceptable early results with valve reconstruction [7]. Due to the thin thickness, this patch maybe a good option for small children.

Training experience

To optimize the technical aspects of AVNeo reconstruction and have the most successful outcomes, ideally the surgeon should have a complete understanding of the aortic valve complex, the technical steps of the procedure, and a hands on experience guided by an experienced AVneo surgeon. Generally, once a surgeon becomes interested, an experienced team provides a lecture and proctors a dry lab where the AVNeo procedure is performed on models (Fig. 9). Ideally, the proctoring surgeon and team then directly assists the first live procedure(s).

Fig. 9 A training model of the aortic root is shown with a single use disposable sizing device. Leaflets are then sutured to the annulus and upon completion, the valve reconstruction can be critiqued

Limitations and unknowns

Single surgeon 10-year outcomes in adult patients with AVNeo are excellent with small numbers of other surgeons reporting similar outcomes with shorter follow-up. However, there are no long-term results in young patients. In younger patients, our expectations are different as they contend with somatic growth issues and increased calcification. Thus, the reproducibility and long-term outcomes with historical repair and reconstructive techniques remain limited. The AVNeo procedure may provide improved longer-term results; however, there are important potential limitations. The AVNeo procedure is technically more difficult in younger patients with smaller aortic annuli and roots. Small technical imperfections such as sinus mis-sizing can lead to earlier failures in younger patients. AVNeo should only be performed in young patients by surgeons with considerable experience with the small aortic root. Currently, autologous pericardium remains the choice for leaflet reconstruction, but the optimal leaflet material remains unknown. The longer-term impact of growth on the neo-aortic valve is unclear. Currently, anticoagulation strategies following AVNeo are based on transcatheter and bioprosthetic valve experiences and optimal short- and long-term anticoagulation strategies remain unknown. Underserved areas of the world may significantly benefit from AVNeo but the use in young patients with rheumatic valve disease remains limited.

Conclusions

Aortic valve neo-cuspidization using the Ozaki technique is an evolving procedure. Though the world experience is limited with regard to the pediatric population, AVNeo sizes and templates will hopefully lead to a versatile solution with reproducible outcomes for young patients with congenital and acquired aortic valve disease. Final conclusions await the long-term results.

Compliance with ethical standards Dr. Baird has no financial relationship with JMODD but has participated in JMODD sponsored training of centers in the Ozaki procedure.

Conflict of interest The authors declare that they have no conflicts of interest. Dr. Baird has no financial relationship with JMODD but has participated in JMODD sponsored training of centers in the Ozaki procedure.

Ethical statements, human and animal rights, and informed consent Not required being a review article.

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