Routine Enlargement of the Small Aortic Root: A Preventive Strategy to Minimize Mismatch

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Background. We routinely use aortic root enlargement (ARE) as part of one strategy to avoid prosthesis–patient mismatch in patients with relatively small aortic roots who are undergoing aortic valve replacement (AVR).

Methods. We performed a retrospective review of 657 consecutive stented AVR patients at a single institution between 1995 to 2001. Of these, 114 (17%) patients underwent ARE. Root enlargement was selectively performed in patients at risk for prosthesis–patient mismatch, defined as calculated projected indexed effective orifice area (iEOA) less than 0.85 cm^2/m^2. This involved extension of the aortotomy between the left and noncoronary cusps, valve implantation, and Dacron patch closure of the aorta, thus permitting replacement with a valve size appropriate to body surface area.

Results. The mean age of ARE patients was 72.5 ± 11.0 years, with 32% aged 80 years or more. Of the patients, 61% were female and 27% had undergone previous cardiac operations. Combined procedures included coronary bypass in 57 patients and mitral repair or replacement in 24. The prevalence of mismatch was less than 3%. The ARE required an average of 19 minutes of additional aortic clamp time. The 30-day mortality was 0.9%. Logistic regression showed perfusion time to be the only independent predictor of mortality.

Conclusions. Our results show that ARE can be performed readily and with minimal added risk relative to standard AVR. We also present a preventive strategy to minimize mismatch predicted at time of operation from the reference value of effective orifice area for a given prosthesis and the patient's size. This includes use of ARE to enhance the potential benefit of AVR.

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A key development in the surgical treatment of aortic stenosis has been the gradual recognition that relief of left ventricular outflow tract obstruction is the goal of operating. Rahimtoola [1] first raised this issue in 1978. Later, Dumesnil and colleagues along with others [2–7] calculated the aortic valve area index required to minimize excess ventricular work at rest and through moderate exercise. Although many cardiac surgeons were trained to choose an aortic prosthesis based solely on the size of the debrided annulus, we now know that the size of the patient is also an important determinant as prevention of prosthesis–patient mismatch has been demonstrated to improve left ventricle mass regression [8–10], postoperative functional class/exercise tolerance [11], and late survival [12–14]. Simply replacing a diseased valve without regard to the size of the patient may diminish the purpose of operating in the first place by implanting a prosthesis that is too small for the patient's needs.

Despite this logic, the relative importance of prosthesis size in aortic valve replacement (AVR) has recently been questioned. Several clinical series [15–17] of AVR recipients have failed to show a survival disadvantage with implantation of small aortic valve prostheses. As a consequence, the implantation of 19-mm labeled prostheses has been routinely advocated in patients with a body surface area (BSA) exceeding 1.7 m^2. For proponents of this approach, the hemodynamic advantage of a stentless aortic valve bioprosthesis in the small aortic root [18, 19] may become irrelevant, and the suggestion that root enlargement techniques may increase early morbidity and mortality has been raised.

To minimize our incidence of mismatch, as defined by indexed effective orifice area (iEOA) of less than 0.85 cm^2/m^2 [2, 6, 7], we choose aortic root replacement, stentless aortic prostheses, or root enlargement [20–24] when the debrided annulus will not admit a stented prosthesis sufficiently large enough to prevent excess ventricular work based on the patient's body size. Simple orthotopic AVR with a stented prosthesis suffices in about 80% of patients in our practice. In the setting of a relatively small aortic root, the choice of operation depends on the patient's age and wishes, the local conditions of the aortic root, as well as the surgeon's judgment and comfort level. We have used ARE routinely and have found this technique to be particularly attractive in older patients and for reoperative or combined procedures. In this article we present our operative strategy aimed to minimize potential mismatch after valve replacement, as well as an operative technique for ARE. Early morbidity and mortality associated with root enlargement are compared to those results we obtained with standard AVR.

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Table 1. Patient Characteristics

Variable	All ARE (n = 114)	All AVR (n = 543)	p Value	Iso ARE (n = 40)	Iso AVR (n = 231)	p Value
Age (y)	72.5 ± 11.0	72.5 ± 12.4	0.943	73.0 ± 12.5	71.6 ± 13.5	0.565
Range	40–93	29–97		40–93	31–94	
≥80 Years	36 (32%)	180 (33%)	0.746	13 (33%)	73 (32%)	0.911
Female sex	70 (61%)	190 (35%)	<0.001	27 (67%)	81 (35%)	<0.001
BSA	1.78 ± 0.26	1.85 ± 0.23	0.005	1.73 ± 0.24	1.85 ± 0.24	0.003
Prior cardiac operations	31 (27%)	136 (25%)	0.663	10 (25%)	44 (19%)	0.425
NYHA class	3.2 ± 0.78	3.0 ± 0.90	0.061	3.2 ± 0.75	2.8 ± 0.91	0.025
I	2 (2%)	37 (7%)		1 (3%)	22 (10%)	
II	20 (18%)	106 (19%)		5 (12%)	52 (22%)	
III	48 (42%)	217 (40%)		20 (50%)	100 (43%)	
IV	44 (38%)	183 (34%)		14 (35%)	57 (25%)	
Ejection fraction	49.5 ± 13.4	50.5 ± 13.2	0.466	50.3 ± 12.3	51.5 ± 12.6	0.579
<30%	17 (15%)	56 (10%)	0.197	17 (15%)	56 (10%)	0.197
Combined procedures	74 (65%)	310 (57%)	0.135	NA	NA	NA
Coronary bypass	57 (50%)	195 (36%)	0.008			
Mitral valve	24 (21%)	108 (20%)	0.710			
Other	13 (11%)	92 (17%)	0.129			

All ARE = all aortic root enlargements; All AVR = all aortic valve replacements without root enlargement; BSA = body surface area (m^2); CAB = coronary artery bypass; Iso ARE = isolated aortic root enlargements; Iso AVR = isolated aortic valve replacements without root enlargement; NA = not applicable; NYHA = New York Heart Association.

Material and Methods

Patient Population

We examined the clinical records of 852 consecutive adult patients in whom we performed aortic valve procedures (isolated and combined) from January 1, 1995, through June 30, 2001, at a single institution. Of this group, 195 patients underwent stentless aortic valve replacement or aortic root reconstruction for a variety of indications, and will not be considered further. The remaining 657 patients underwent stented aortic valve replacement either with (all ARE, 114 patients, 17%) or without (all AVR, 543 patients, 83%) aortic root enlargement. We assessed the clinical characteristics and early outcomes obtained in these two groups by retrospective review according to the guidelines of the Society of Thoracic Surgeons Database (http://www.sts.org) supported by our institution. Perioperative analysis included assessment of 30-day mortality (in hospital and out of hospital), stroke, reoperation for bleeding, and myocardial infarction. To minimize potential variation between these groups as a result of surgical complexity, we examined two additional subgroups that were more comparable: those who underwent isolated aortic valve replacement with aortic root enlargement (ARE; 40 patients) or without (AVR; 231 patients).

Table 1 shows the clinical characteristics of the 657 patients who underwent stented aortic valve replacement with or without aortic root enlargement. This table also shows the clinical characteristics of the 271 patients who underwent isolated aortic valve replacement with or without root enlargement. The mean age of the entire population was 72.5 years, and 33% were aged 80 years or more. Approximately 75% of patients had at least New York Heart Association class III symptoms preoperatively. In addition to aortic valve replacement, 38% (252 patients) had coronary bypass procedures performed at the same time; 20% (132 patients) had concomitant mitral valve repair and or replacement; and 16% (103 patients) had other procedures Prior cardiac surgery had been performed in 25% (167 patients).

Operative Techniques

We routinely use normothermic cardiopulmonary bypass, left atrial venting, and intermittent cold blood cardioplegia. The types and frequency of stented valves used are included in Table 2. We select prostheses on the basis of the patient's age and preference, as well as the surgeon's judgment. Preoperatively, we calculate a minimum prosthetic aortic valve size based on a given patient's BSA to prevent prospective mismatch as defined by an indexed effective orifice area of at least 0.85 cm^2/m^2. This method used to predict and define mismatch at the time of valve implantation has been previously validated [7]. To achieve this goal, we use published normal reference values of effective orifice area (EOA) for each valve type and size [2, 3, 6]. If the debrided aortic annulus accommodates at least this size, we proceed with standard aortic valve replacement. If the annulus is too small in relation to the patient's body size, we either enlarge the root as described below or choose a stentless valve or perform aortic root reconstruction. In general, the ARE technique described below can gain one to two incremental valve sizes. Extremely small roots are best managed with stentless valves or root replacement. As an example, consider a patient weighing 100 kg and measuring 6 feet in height (BSA = 2.2.m^2). Use of a 23 Hancock II (Medtronic, Minneapolis, MN) bioprosthesis with a published in vitro EOA of 1.81 cm^2 would result in

Table 2. Distribution of Valve Types Among Stented Aortic Valve Replacements

Valve Type	*n*	%
Stented bioprosthesis		
Hancock-I	207	31.5
Hancock-II	134	20.4
Medtronic-Hall	73	11.1
Medtronic-Mosaic	29	4.4
CE-Pericardial	151	23.0
CE-Porcine	5	0.8
Mechanical		
St. Jude Medical	51	7.7
Carbomedics	7	1.1
Total	657	100

predictable mismatch, as the iEOA would equal 0.80 cm^2/m^2. A 25-mm Hancock II valve (EOA = 2.1), however, will suffice, as the iEOA in this patient now equals 0.93cm2/m2. In this example, we would proceed with implantation of at least this size and type of prosthetic valve with or without root enlargement. If, however, the annular dimensions were too small and could not be projected to accommodate a 25-mm stented valve after root enlargement, we might choose either root replacement or subcoronary stentless valve implantation based on the local conditions of the aortic root and coronary ostia as well as the surgeon's judgment.

We generally rim the annulus with 12 to 15 interrupted 2-0 Ethibond (Ethicon, Somerville, NJ) mattress sutures, with or without Teflon (Impra Inc, a subsidiary of L.R. Bard, Tempe, AZ) pledgets. We implant the majority of stented valves in the supraannular position; however, we occasionally place mechanical valves in the so-called intraannular position. We enlarge the aortic annulus as depicted in Figure 1. We extend the standard oblique aortotomy down through the commissure between the left and noncoronary sinuses, about 1 to 1.5 cm into the base of the anterior mitral leaflet, *without* entering the left atrium (the atrial wall can be gently swept free of the aortic root). We cut a standard 30-mm Hemashield (Boston Scientific, Natick, MA) tube graft to form a long elliptical patch employed both to enlarge the left ventricular outflow tract and to close the entire aortotomy. The greatest width of this patch is approximately 2 cm. We sew the patch in place with a single running 3-0 Prolene (Ethicon, Somerville, NJ) to generously invert the suture line. When the lower half of the patch is sewn in place, we turn our attention to the aortic valve sutures. These are placed in a routine manner as described above until we reach the edges of the patch. Here we place pledgetted sutures from outside the aorta to inside in a gradual curvilinear direction so that the sutures inside the patch maximally use the span of the patch (Fig 1e). We use pledgets here to avoid crimping the Hemashield patch. After the valve is tied in place, we extend the patch over the remainder of the open aortotomy and trim the patch to fit. We then finish the aortotomy patch closure with the running 3-0 Prolene sutures. This technique enables us to seat a supraannular valve one or two sizes larger than the original annulus could accommodate.

Statistical Analysis

Data were analyzed with SPSS statistical software (SPSS, Chicago, IL), with probability values less than 0.05 considered significant. Distributions of continuous variables were expressed as mean ± standard deviation. Comparisons between aortic root enlargement recipients and

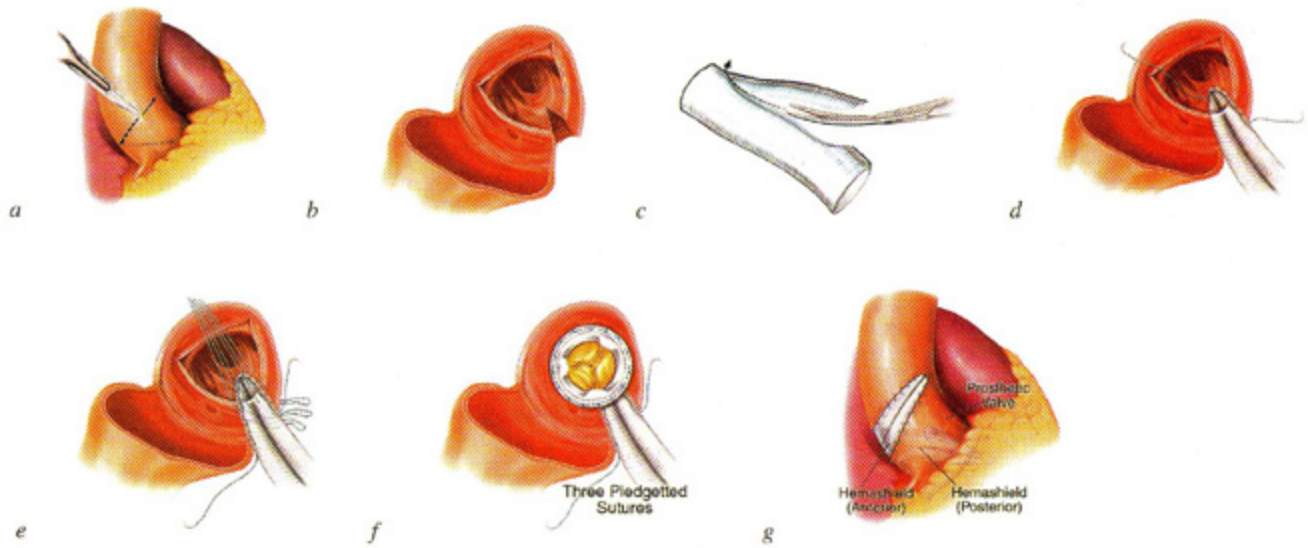

Fig 1. Operative technique of aortic root enlargement. A standard oblique aortotomy (a) is extended down through the commissure between the left and noncoronary sinuses, into the base of the anterior mitral leaflet (b). A 30-mm Hemashield tube graft is cut to form a long elliptical patch (c). The patch is sewn with a single running 3-0 Prolene generously inverting the suture line (d). Pledgetted sutures are placed from outside the patch to within in a curvilinear direction to maximally use the span of the patch (e). The aortic prosthesis is seated in a supraannular position (f). The aortotomy is closed in its entirety with the Hemashield patch (g).

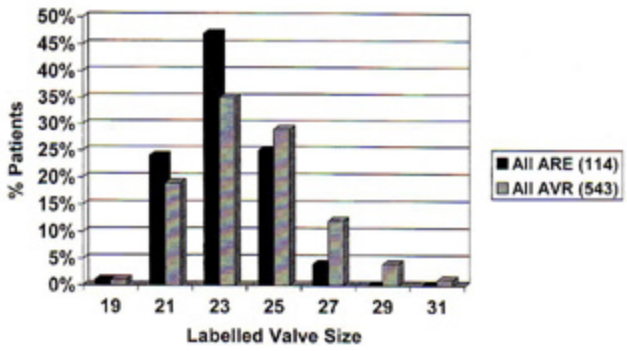

Fig 2. Labeled valve size distribution of all aortic valve replacements (AVR) with and without aortic root enlargement (ARE).

nonrecipients were performed using unpaired Student's *t* tests. Comparisons of categorical variables were performed using the χ^2 test. In addition, stepwise logistic regression analysis of all 657 stented aortic valve replacement patients was performed to determine independent preoperative and intraoperative predictors of 30-day mortality.

Results

The distribution of labeled valve sizes is demonstrated graphically in Figure 2 and summarized in Table 3. The mean labeled aortic valve size was 23.9 ± 2.2 in all AVR patients and 23.2 ± 1.7 in all ARE patients. The median labeled size in both groups was 23 mm. A prosthesis labeled 23 mm or larger was used in 75% of the all ARE patients. A valve size labeled 19 was implanted in 1 (0.9%) ARE patient. This was a unique case requiring enlargement of a "nickel-sized" annulus in an adult to accommodate our smallest stented valve, which resulted, however, in mismatch (iEOA = 0.84 cm^2/m^2). Root replacement, in this instance, may have been a better solution. A valve size labeled 19 was implanted in 4 (0.7%) AVR patients. These patients were of small BSA and all had iEOAs exceeding 0.85 cm^2/m^2. The indexed effective orifice area in all AVR patients was 1.24 ± 0.31 cm^2/m^2 and in all ARE patients was 1.18 ± 0.23 cm^2/m^2.

Table 3. Indexed Prosthetic Valve Sizing

Variable	ARE (n = 114)	AVR (n = 543)	p Value
Bioprosthesis	92 (81%)	434 (80%)	0.851
Mean labeled size (mm)	23.2 ± 1.7	23.9 ± 2.2	<0.001
Range	19–27	19–31	
Median	23	23	
Labeled size ≥23 mm	86 (75%)	434 (80%)	0.271
Indexed EOA (cm^2/m^2)	1.18 ± 0.23	1.24 ± 0.31	0.009
Indexed EOA < 0.85 cm^2/m^2	3 (2.6%)	13 (2.4%)	0.885

ARE = aortic root enlargement; AVR = aortic valve replacement without root enlargement; Indexed EOA = indexed effective orifice area (based on previously published reference values for each individual prosthetic valve type and size implanted at operation divided by patient body surface area).

The difference between the two groups is statistically significant and can be explained by acknowledging that those patients who did not require ARE had either appropriately matched, or larger, annular dimensions per BSA. Naturally, larger valves could be implanted. Those patients requiring ARE, by definition, had inappropriately small annular dimensions per BSA and were enlarged to achieve a more suitable dimension per BSA (iEOA ≥0.85 cm^2/m^2). Approximately 2.5% in either group had mismatched valves implanted.

Table 4 confirms the additional time required for root enlargement. Mean ischemic time for isolated aortic valve replacement was 48 minutes. Root enlargement added approximately 19 minutes to this time. We performed well over half of isolated AVRs (with or without root enlargement) using limited upper "mini-sternotomies." In 2001, 70% of isolated aortic valve operations were performed through these smaller incisions. The addition of root enlargement did not increase the incidence of 30-day mortality, stroke, reoperation for bleeding, or myocardial infarction.

A total of 14 preoperative and intraoperative characteristics were entered into a stepwise logistic regression model to predict 30-day mortality among all 657 stented AVR patients. These included age, sex, BSA, New York Heart Association functional class, ejection fraction, previous cardiac operation, aortic clamp time, cardiopulmonary bypass time, concomitant coronary bypass, concomitant mitral replacement, concomitant mitral repair, root enlargement, indexed internal orifice area, and indexed effective orifice area. Cardiopulmonary bypass time (p = 0.001) emerged as the only independent predictor of mortality.

Comment

This review demonstrates that stented aortic valve replacement can be performed without causing prosthesis–patient mismatch in the vast majority (>97%) of patients who undergo operation. It also demonstrates that aortic root enlargement by the method described adds about 20 minutes of aortic clamp time, but adds no increase in morbidity or early mortality. In fact, we have long considered this technique a simple way to add value to aortic valve replacement and an alternate method of closing the aortotomy.

Our belief was strengthened when Dumesnil and colleagues [2], Pibarot and Dumesnil [5], and Pibarot and associates [6] pointed out that in the smaller prosthetic sizes, an increase of one valve size chronically reduced cardiac work by approximately 20%. Furthermore, preventing mismatch has been shown to improve left ventricle mass regression [8–10], postoperative functional class/exercise tolerance [11], and late survival [12–14]. However, other investigators [15–17] have reported no deleterious effect on long-term survival among patients who received mismatched valves. This belief was strengthened by the recent review by Medalion and colleagues [15] of data from the Cleveland Clinic, which demonstrated no association between apparent mis-

Table 4. Perioperative Outcomes

Variable	All ARE (n = 114)	All AVR (n = 543)	p Value	Iso ARE (n = 40)	Iso AVR (n = 231)	p Value
Aortic clamp time (min)	87.0 ± 26.5	65.0 ± 24.4	<0.001	67.0 ± 15.8	48.2 ± 12.0	<0.001
CPB time (min)	106.8 ± 31.1	82.2 ± 31.4	<0.001	84.5 ± 18.5	63.6 ± 22.8	<0.001
Stroke	4 (3.5%)	30 (5.5%)	0.378	0 (0%)	8 (3.5%)	0.234
Reoperation for bleeding	5 (4.4%)	25 (4.6%)	0.919	0 (0%)	5 (2.2%)	0.349
Myocardial infarction	2 (1.8%)	1 (0.2%)	0.211	0 (0%)	1 (0.4%)	0.678
30-Day mortality	1 (0.9%)	22 (4.1%)	0.010	1 (2.5%)	10 (4.3%)	0.590

All ARE = all aortic root enlargements; All AVR = all aortic valve replacements without root enlargement; Iso ARE = isolated aortic root enlargements; Iso AVR = isolated aortic valve replacements without root enlargement; CPB = cardiopulmonary bypass.

match and postoperative mortality. It is imperative to note, however, that in this study, the definition of mismatch was based on the internal geometric orifice area of the prosthetic valve indexed for BSA. In a more recent study [7], it has been demonstrated that indexed geometric orifice area grossly overestimates and correlates poorly with the iEOA and therefore should not be used to identify patients who have a high transvalvular gradients on the basis of prosthesis–patient mismatch. Likewise, assessment of prosthetic valve size alone does not correlate with transvalvular gradients. Instead, mismatch was reliably predicted by using iEOA based on the reference value of the aortic prosthesis divided by the patient's BSA. This constant also predicted resting and exercise postoperative gradients validated by measuring resting and exercise iEOA derived with Doppler echocardiography. Therefore, the review by Medalion and colleagues may not have identified those patients with true prosthesis–patient mismatch. Is valve size alone important? No. It is the relationship of the hydrodynamic properties of a given valve type and size (EOA) indexed to patient body size (BSA) that accurately predicts mismatch. A 19-mm pericardial tissue valve can be an appropriate choice in a small adult patient weighing 50 kg.

Nonetheless, we have persisted in our efforts to prevent mismatch, because we can implant larger valves safely and because it makes physiologic sense to minimize outflow tract obstruction. The fourth power inverse relationship between resistance and radius (Poiseuille's law) probably explains why even the modest increase in diameter achieved with a stenotic prosthesis confers substantial benefit on patients with aortic stenosis. However, the value point in aortic valve replacement resides where the maximum increase in LV outflow size intersects the minimum operative risk. In our hands, aortic root enlargement often fits this bill because we can perform it more quickly than the other options (root replacement and stentless valves), and it provides very secure aortic closure.

Techniques of aortic root enlargement in the adult have been previously described and are commonly attributed to Manouguian and Seybold-Epting [20] and to Nicks and colleagues [21]. Several surgical series used these techniques [22–24] and demonstrated relative success, but at the expense of increased operative risk. We were particularly concerned by the increased mortality (7.1% vs 3.5%) that Sommers and David [23] reported in their series of aortic root enlargements versus aortic valve replacement alone. This important retrospective study provoked us to review our own experience with ARE. Comparing clinical profiles reveals that our patients were nearly 10 years older, were at least as complex as measured by adjunctive procedures, and were in similar New York Heart Association classes; in addition, 27% of our patients had previously undergone cardiac operations. Although the series reported by these investigators predates our own, we believe that the key difference that explains their higher mortality in root enlargement cases can be attributed to technique. They use a small teardrop-shaped patch of pericardium that is then sutured in only at the base of the aortotomy. This may be the culprit predisposing to dangerous bleeding, as was their experience. We use a section cut from a 30-mm Hemashield tube graft that was long enough to close the entire aortotomy. This material is readily available and quickly prepared. It is generally stronger and more uniform than pericardium, and it starts with the curved shape of the aorta built into it. The generous inverted suture lines on each side of the patch prevents troublesome bleeding problems. In fact, adding this material permits us to take deeper "bites" into the occasionally friable aortic wall without increasing tension on the aortic closure. Finally, we believe that the wide exposure gained by patch enlargement facilitates suture placement and seating of a stented prosthesis in elderly patients with heavy calcification of the sinotubular rim or, particularly, the coronary ostia, which can preclude or make dangerous the total root replacement and insertion of stentless valves.

Our study is limited by its failure to provide long-term follow-up. These results do not permit inferences regarding long-term survival or the functional improvement attainable with root enlargement. Such limitations, however, do not affect our conclusion that patch aortic root enlargement is a safe technique that can improve the quality of aortic valve replacement in patients with a small root. We encourage prospective operative strategies to minimize predictable mismatch, as well as a renewed interest in aortic root enlargement in patients with relatively small aortic roots.

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DISCUSSION

DR JOHN D. OSWALT (Austin, TX): I want to ask you some technical questions. As I remember the Manouguian description, he described going down into the mitral valve and entering into the left atrium. So you are able to avoid that almost routinely? Is that my understanding from what you said?

DR CASTRO: We have not found it necessary to enter the left atrium in order to complete an effective enlargement incision between the divided commissure. We have found it very simple to separate the underlying left atrium from the base of the aorta with a gentle sweep of the scissors, so that, in the vast majority of cases, the atrium is not opened. Inadvertent entry into the atrium, however, must be recognized for obvious reasons. This is then closed in much the same manner in which Dr Manouguian originally described.

DR OSWALT: And then my other question is, in your series, where do you see the use of a stentless valve? As with our previous paper, where we saw such good flow and good EOAs represented from that, where do you see that represented in your practice?

DR CASTRO: This is a very difficult question to answer, as our own indications for use of stentless valves continues to evolve with the availability of the Medtronic Mosaic valve in our practice. We have employed stentless technology, either as subcoronary implants or root replacements, in approximately 15% to 20% of our aortic valve operations, preferring them to stented valves in the younger patient who wishes to be free of anticoagulation issues. Where root enlargement buys us the simplest or quickest method to upsize a valve one or two sizes, stentless valves afford relatively larger upsizing (or more EOA per real estate of aortic annulus) in those patients with unusually small roots. The local conditions of the aorta also weigh heavily on our decision. Subcoronary implantation clearly requires more technical attention and may be impossible in the presence of extensive aortic wall calcification; root replacements, in our hands, tend to have more bleeding problems postop and are made dangerous in the setting of ostial calcification more commonly seen in the elderly patient. These guidelines are heavily dependent on surgeon experience, as Dr Neil Kon has demonstrated outstanding results with stentless root replacement techniques. It is important, however, for all surgeons to have a personalized strategy in their heads before valve replacement, as the small, complex, and high-risk root usually masks itself as a routine AVR before opening up the aorta.