MASTERS OF MEDICINE IN SURGERY (PART III) DISSERTATION

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MECHANICAL AORTIC VALVES AND THE SMALL AORTIC ROOT

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DISSERTATION SUMMARY:

The ideal approach towards aortic valve replacement surgery in the small aortic root, and the concept of prosthesis-patient mismatch remains a topic of much controversy and debate. Aortic prosthesis-patient mismatch when implanting small prosthetic aortic valves has long been believed to negatively impact on postoperative hemodynamic status, residual aortic stenosis, symptomatic improvement, regression of left ventricular hypertrophy, as well as long term results and survival. Mechanical aortic valve replacement is today still predominantly utilized in the small aortic root in most centers. There are now various attractive alternative surgical modifications available, all striving to alleviate or reduce prosthesis-patient mismatch with its proposed deleterious effects, and is very effective in individual experienced hands.

This review scrutinizes current knowledge regarding aortic valve surgery in the small aortic root and the concept of prosthesis-patient mismatch on the postoperative hemodynamic status, functional capacity, morbidity and mortality.

In the University of Alberta Hospital experience over a 5 year period, no statistically significant difference or any disadvantage was found to using small mechanical or stented bioprosthetic valves in the face of the small aortic root as far as early postoperative aortic prosthetic valve gradients are concerned. The problem and shortfall with this approach is that it considers only one postoperative variable.

When further looking at the particular group of patients in question, ie. those patients who by definition have a small aortic root, and had small prosthetic aortic valves implanted, and when considering the individual patient indexed EOA's, it is clear that almost all of these small valves are stenotic with the potential for prosthesis-patient mismatch.

Many surgeons around the world, including the University of Alberta Group, feel that a greater procedure when dealing with aortic valve surgery in the face of a small aortic root is not necessarily indicated for optimal results. However, postoperative prosthetic aortic valve stenosis and prosthesis-patient mismatch with its potential deleterious effects, exercise intolerance and sub-optimal long term survival, is a very real problem, and I feel that in particular the simple Nicks-Nunez aortic root widening procedure should be used much more liberally. However, single every case should be individualized and scrutinized according to specific indications, surgical experience and results.

TEXT:

Introduction:

The approach and surgical attitude towards the small aortic root remains a topic of much controversy and intense surgical debate. Aortic prosthesis-patient mismatch occuring when implanting small prosthetic aortic valves has long been believed to negatively impact on post aortic valve replacement hemodynamic status, residual aortic valve stenosis, symptomatic improvement, regression of left ventricular hypertrophy, as well as long term results and survival. Mechanical aortic valve replacement is still utilized in most of these cases despite the numerous concerns about these mechanical valves causing some degree of obstruction and hence prosthesis-patient mismatch, but these mechanical valves are still used mainly due to the ease of their implantation (1).

Homografts, autografts, stentless valves and various other additional procedures and modifications have been used with increased frequency for aortic valve replacement to attempt to alleviate this problem of prosthesis-patient mismatch and its sequelae, but these operations also have their set of own individual indications and potential complications.

This review scrutinizes aortic valve replacement surgery in the presence of a small aortic annulus and root, and specifically mechanical aortic valve replacement and the concept of prosthesis-patient mismatch.

Prosthesis-patient mismatch and the small aortic root:

When the adult aortic valve annulus cannot accommodate a prosthetic aortic valve of a size 21mm or larger, a small aortic root is considered to be present, but this also needs to be related to the patient's own body surface area or body mass index, and various other factors. Placement of a smaller prosthetic aortic valve in larger and more active patients in the usual fashion will leave the patient with potential residual aortic stenosis, high postoperative prosthetic valve gradients and so-called prosthesis-patient mismatch which is believed to have a significant negative impact on the long-term results of aortic valve replacement surgery.

Rahimtoola first described prosthesis-patient mismatch as: "Mismatch can be considered to be present when the effective prosthetic valve area, after insertion into the patient, is less than that of a normal human valve" (1).

Doppler echocardiographic studies have demonstrated that most prosthetic aortic valves are at least mildly stenotic as compared to the normal native human aortic valve, and that relatively high postoperative prosthetic valve gradients can be observed, despite normal prosthesis function, and that in most instances these gradients are due to prosthesis-patient mismatch (1-14).

Transvalvular gradients are essentially determined by two factors as per the Gorlin equation: the aortic valve area (AVA) or so-called effective orifice area (EOA) of the

specific prosthetic aortic valve (as provided by the manufacturers) and the transvalvular flow. Transvalvular flow is in turn related to cardiac output (CO), which at rest is largely determined by body surface area (BSA). Therefore, the variable that best correlates with postoperative rest and exercise gradients, is the indexed EOA, which is the EOA of the valve divided by the BSA of the patient (3,4,12-14). Prosthesis-patient mismatch is believed to occur when the indexed EOA is reduced, or when the prosthesis orifice size is too small in relation to the size of the patient's body. Prosthesis-patient mismatch is recognized by the American Society of Thoracic Surgeons and identified as nonstructural dysfunction (15,16), and mismatch is deemed as a functional hemodynamic abnormality, rather than being due to an intrinsic defect of the prosthetic valve (14).

It is generally accepted that moderate aortic stenosis is present when the indexed EOA of the native aortic valve is < 0.9 cm²/m², and severe if < 0.6 cm²/m² (17,18). Consequently it has been shown that to avoid any significant aortic valve gradient at rest or during exercise, the indexed EOA of the aortic valve prosthesis should ideally be greater than 0.85-0.9 cm²/m² (2,3,12-14). Therefore, one of the main objectives of aortic valve replacement surgery should logically be to attempt to ensure that the indexed EOA of the prosthetic aortic valve following the operation is above 0.85-0.90 cm²/m² as to avoid any residual aortic valve stenosis.

Prosthesis-patient mismatch is more likely to occur in the patient with a larger BSA, aortic valvular stenosis as the predominant aortic valve lesion, older age and smaller prosthetic valve size or EOA (1,3,4,14). Larger patients are predisposed to prosthesis-

patient mismatch due to usual high cardiac output requirements, and that their pathology possibly produces greater valve annulus narrowing in relation to their body size as compared to in smaller patients. Patients with aortic valve stenosis frequently exhibit annular calcification and fibrosis as well as significant left ventricular (LV) hypertrophy, which all can reduce the size of the aortic valve annulus leading to and resulting in insertion of a prosthesis too small relative to the patient's body size and hemodynamic requirements. The incidence of aortic stenosis is also more common in older patients, and they usually have more pronounced annular calcification and fibrosis as well as decreased aortic and aortic valve annular compliance, which further compounds the problem.

The internal diameter and EOA of the prosthetic valve is less than the aortic valve tissue annulus diameter, and the orifice area which a normal native aortic valve would have in the same aorta as the prosthesis is usually inserted within the native aortic valve annulus and the prosthetic valve has its own structural support apparatus. This structural support apparatus of stented bioprosthetic and mechanical prosthetic valves causes relative obstruction to blood flow, and it has been shown that in these valves the EOA available for blood flow represents only 40-70% of the total area occupied by most prosthetic valves (19-21), although manufacturers are continually working at producing improved newer generation valves which are less obstructive in nature and with superior hemodynamic properties.

Stentless bioprosthetic valves are also inserted within the aorta and aortic valve annulus, but still provides a larger EOA in relation as compared to other prosthetic valves with a more substantial structural support apparatus (13,14,22-25), thus allowing for insertion of slightly larger valves as compared to the mechanical and stented bioprosthetic valves, provided there is no buckling of the inlet of these stentless valves during their insertion.

The incidence of prosthesis-patient mismatch consequently increases with diminishing prosthesis size, and it is widely recognized that average adult patient with an aortic prosthetic valve size of ≤ 21mm tend to have much higher postoperative gradients (8,14,26,27). Many studies have demonstrated that prosthesis-patient mismatch is not a rare phenomenon, and is usually observed in > 50% of patients with a stented aortic valve bioprosthesis and a relatively conservative indexed EOA ≤ 0.85 cm^2/m^2 (4,14,28), but the hope is that the newer and improved superior valve designs and technology should lower this figure substantially.

Impact of prosthesis-patient mismatch:

The main consequence of and problem with prosthesis-patient mismatch is to generate a high postoperative transvalvular gradient through a normally functioning prosthetic valve, which consequently results in increased LV work, thus jeopardizing the regression of LV hypertrophy initially caused by the native aortic valve lesion. An expression of the potential severity of prosthesis-patient mismatch is given by the relation showing that the

transvalvular gradient increases exponentially with a decrease in indexed EOA, and that a small decrease in indexed EOA might result in a relatively large increase in gradient (2,3,13,14). Pibarot and Dumesnil demonstrated that long-term follow-up of their patients showed clinical and gradient deterioration only in cases with mismatch, and that the greatest deterioration in cardiac index and gradients are seen in patients with the most severe mismatch (ie. Indexed EOA ≤ 0.65 cm^2/m^2) (13,14). Further studies from this group also show that the mean gradient, as well as the increase in mean gradient during maximal exercise, can also be directly related to the indexed EOA calculated at rest. These exercise studies also demonstrated that the EOA of a bioprosthesis, and particularly in the case of stentless valves (due to stretch, as these valves are more pliable), has the potential to increase during exercise, and that as a consequence the observed increase in gradient is substantially less ($\approx 25\%$) than what would have been observed if the EOA had remained constant during exercise as is the case in bioprosthesis (both stented and stentless) that have become calcified over time or in the case of mechanical prosthesis which have a greater increase in gradient during exercise (12-14). Indeed, recent studies performed in patients with mechanical valves suggest that the EOA of these patients does not increase during exercise, resulting in a relatively greater increase in gradient (29,30).

The impact of mismatch may also be overestimated in patients with smaller aortic roots due to the pressure recovery phenomenon downstream to native or prosthetic aortic valves in patients with an inherently small diameter aorta as compared to patients with a larger diameter aorta (31-33). Therefore, given a similar indexed EOA, patients with a

smaller diameter aorta will have less energy loss and less of a burden on their LV than those with a larger diameter aorta.

LV hypertrophy has long been recognized as an important risk factor and predictor of survival as well as a major determinant of systolic and diastolic function and individual patient exercise capacity (34-36). Residual pressure gradients cause a delay in regression of LV hypertrophy following aortic valve replacement, and the extent of LV muscle mass regression has been shown to be highly dependant on the type and size of aortic valve prosthesis used as well as their hemodynamic performance (37-40).

Barner et al (43) demonstrated that regression of LV hypertrophy after aortic valve replacement is better in patients with a prosthesis size of > 21mm (≈ 21%) than in patients with a prosthesis size of ≤ 21mm (≈ 8%), and that the mean wall thickness of the LV was directly related to the pressure gradient across the prosthetic aortic valve. Other studies also demonstrate that aortic valve replacement with a stentless bioprosthesis is associated with a greater decrease in transvalvular gradient and LV wall stress, as well as with more complete regression of LV hypertrophy, compared with stented valves (13,14,38). Del Rizzo et al (39) demonstrated in a series of 1103 patients that there is a strong relation between indexed EOA and the extent of LV mass regression. At 3 years after operation LV mass index had decreased by 23% on average in patients whose indexed EOA was > 0.8 cm^2/m^2, as compared with 4.5% (p=0.0001) in patients with an indexed EOA < 0.8 cm^2/m^2. In contrast, no difference was noted between the patients with an indexed EOA between 0.8 and 1.0 cm^2/m^2 (24% versus 22%).

Interestingly, although LV hypertrophy is recognized as an important risk factor and predictor of survival as well as a major determinant of systolic and diastolic function and exercise capacity, this LV hypertrophy secondary to valvular pathology, is different to the LV hypertrophy observed in hypertensive heart disease, where the muscle hypertrophy also shows an important proportion of interstitial fibrosis and the hypertrophy also has a neurohormonal component. The hypertrophy due to valvular disease could be, and is quite different and more directly related to an increased hemodynamic burden, in which case the hypertrophy could be more physiologic in nature, show less fibrosis, and thus not have the same negative impact on long-term prognosis as is the case in LV hypertrophy secondary to hypertensive heart disease. Indeed, it has been shown that the physiologic hypertrophy due to exercise is directly related to the increased burden related to the intensity of training, and this physiologic hypertrophy does not carry any long-term negative effects (14,36).

Postoperative improvement in physical capacity and exercise capacity, are very important goals of aortic valve replacement as it directly influences symptomatic status, quality of life, rate of re-employment and late mortality (14,41,42).

Exercise capacity results are conflicting, with some studies demonstrating that prosthesis size is an independent predictor of exercise tolerance following aortic valve replacement (14,43,44). De Carlo et al reported that among patients with a 21mm St. Jude mechanical valve, those with a BSA ≥ 1.70 m^2 had significantly lower exercise tolerance than those with BSA ≤ 1.70 m^2 (45). Furthermore, the indexed EOA was an independent predictor

of exercise tolerance variables. On the other hand, studies of patients with bioprosthetic valves show that maximal exercise capacity, as estimated by maximal workload, peak oxygen consumption or anaerobic threshold, is similar between patients with an indexed EOA ≤ 0.85 cm²/m² and > 0.85 cm²/m² (12-14).

It has also been shown that the limitation of exercise capacity in patients with small aortic prosthetic valves is likely the result of other or additional factors besides the moderate increase in gradients with exercise, and furthermore, these gradients represent some overestimation because of the lack of correction for left ventricular outflow tract velocities in the Bernoulli equation, and also depends on which exercise protocol is used (46). It is believed that, and shown in several studies that mortality in patients receiving a small ($\leq$ 21mm) aortic valve prosthesis (47-50), and that a smaller valve size may actually be an indicator of additional risk factors, such as a senescent aortic stenosis, a small calcified aortic root, marked LV hypertrophy, smaller BSA, and possibly a technically more difficult operation often requiring longer aortic cross-clamp times (48).

From these findings it is evident that further longitudinal studies are necessary to determine whether the higher mortality associated with smaller valve sizes is due to prosthesis-patient mismatch or to the other aforementioned factors. To clarify this it is important to report the results for the indexed EOA and to include them in the risk factor analysis. In contrast to studies of native aortic valves showing that aortic stenosis is generally associated with higher morbidity and mortality rates when the indexed EOA $<$ 0.60 cm²/m² (17,18), numerous studies following aortic valve replacement have failed to

demonstrate any significantly negative impact of prosthesis size and prosthesis-patient mismatch on short and medium-term survival of these patients (4,51-55).

Approach to the small aortic root and the prevention of mismatch:

The surgical attitude and ideal approach towards the small aortic root remains a topic of much controversy and intense surgical debate. Mechanical aortic valve replacement is today still predominantly utilized in most centers and cases, despite the concerns about these mechanical valves causing some degree of obstruction and hence so-called prosthesis-patient mismatch, mainly due to the ease of their implantation (1). However, today there are several surgical options and modifications available (Table 1), all aiming to optimize postoperative indexed EOA ideally above 0.85-0.90 cm^2/m^2 as to avoid residual aortic valve stenosis and prosthesis-patient mismatch. The use and choice of these different approaches are dictated by personal surgical or center experience, individual preference, postoperative results, and the perceived added risk of employing a greater or more complex procedure.

Table 1: Surgical options and modifications in the small aortic root

Mechanical prosthetic valve replacement:	Bileaflet valves
	Tilting disc valves
	Valve orientation in the root
	Hemodynamic plus valves
	Supra-annular valves
Stented bioprosthetic valve replacement:	Intra-annular valves
	Supra-annular valves
Riding the valve up above the annulus in the non-coronary sinus (partial supra-annular valve placement)	
Root widening procedures:	Nicks-Nunez
	Rittenhaus-Manougian
	Konno-Rastan
Apico-aortic conduit	
Mechanical dilatation of the small aortic annulus	
Associated septal myectomy	
Homograft valve replacement	
Stentless bioprosthetic valve replacement	
Autograft valve replacement (Ross procedure)	
Aortic valve repair procedures	

Pibarot and Dumesnil suggested a simple three-step algorithm that can be used in the operating room to prevent prosthesis-patient mismatch when using any of the specific aortic valve prostheses available (14).

Step 1: Calculate the patient's BSA from weight and height using the equation or chart proposed by Dubois (BSA = [{weight(kg) x 0.425} x {height(cm) x 0.725}] x 0.007184) (56). Step 2: Determine the minimal requirement for prosthetic valve EOA to avoid prosthesis-patient mismatch for the particular BSA. Pibarot and Dumesnil compiled a table (Table 2) which shows the determination of the minimal valve EOA required to ensure an indexed EOA of > 0.85 cm^2/m^2 (which is considered to be ideal), > 0.80 cm^2/m^2, or > 0.75 cm^2/m^2, given the patient's BSA as calculated in step 1. The choice between 0.85, 0.80 and 0.75 cm^2/m^2 is based on what is deemed to be the minimal requirement for a given patient, with the knowledge that 0.85 cm^2/m^2 or higher is the optimal value for better hemodynamics. Step 3: Select the type and size of prosthesis that has reference values for EOA (as produced by the specific different prosthesis type manufacturers) greater or equal to the minimal EOA value obtained in step 2. The manufactures reference values should be as representative as possible of the in vivo performance of the prostheses. Manufacturers also have in virto values derived from pre-marketing studies, but these values usually overestimate in vivo values by 10% - 15%, but otherwise correlate well with in vivo values (2, 8). One notable exception is stentless valves, whose in vitro values for EOA grossly overestimate in vivo values and cannot be relied on. Therefore, both in vitro and in vivo values for EOA should readily be provided by the manufacturers, as they become available. Except in the case of stentless valves, in

Table 2: Three Easy Steps to Avoid Prosthesis-Patient Mismatch

Step I: Calculate the patient's body surface (BSA) area using the formula:
BSA = [{weight(kg) x 0.425} x {height(cm) x 0.725}] x 0.007184)

Step II: Determine the minimal requirement for prosthetic valve effective orifice area (EOA) to avoid prosthesis-patient mismatch.

Patient BSA (m^2)	Minimal Valve EOA (cm^2) for Indexed EOA >0.85cm^2/m^2 (Ideal)	Minimal Valve EOA (cm^2) for Indexed EOA >0.80 cm^2/m^2	Minimal Valve EOA (cm^2) for Indexed EOA >0.75 cm^2/m^2
1.30	1.11	1.04	0.98
1.35	1.15	1.08	1.01
1.40	1.20	1.12	1.05
1.45	1.23	1.16	1.09
1.50	1.28	1.20	1.13
1.55	1.32	1.24	1.16
1.60	1.36	1.28	1.20
1.65	1.40	1.32	1.24
1.70	1.45	1.36	1.28
1.75	1.49	1.40	1.31
1.80	1.53	1.44	1.35
1.85	1.57	1.48	1.39
1.90	1.62	1.52	1.43
1.95	1.66	1.56	1.46
2.00	1.70	1.60	1.50
2.05	1.74	1.64	1.54
2.10	1.79	1.68	1.58
2.15	1.83	1.72	1.61
2.20	1.87	1.76	1.65
2.25	1.91	1.80	1.69
2.30	1.96	1.84	1.73
2.35	2.00	1.88	1.76
2.40	2.04	1.92	1.80
2.45	2.08	1.96	1.84
2.50	2.13	2.00	1.88

Step III: Choose a prosthesis using reference values for EOA of different types and sizes of prostheses as provided by the manufacturers.

vitro values could temporarily be used as a reference until the in vivo values can be provided. Also the in vivo values should ideally be taken at one year after the valve replacement operation, as hemodynamic data may change in the first year. Finally, it should be remembered that in vivo EOA values for bileaflet valves may artifactually be underestimated when evaluated by Doppler echocardiography owing to localized high velocity jets, and hence in this case a value for EOA lower than the reference value does not necessarily indicate prosthesis dysfunction (14).

Table 1 shows the various surgical options and modifications available when replacing the aortic valve in the face of the small aortic root. The ideal end result is to optimize the particular prosthesis postoperative indexed EOA ideally above 0.85-0.90 cm^2/m^2 as to avoid residual aortic valve stenosis and the potential ill effects of prosthesis-patient mismatch. If a particular prosthesis fails to meet this requirement, a different type of prosthesis with better hemodynamic performance, a larger prosthesis size, or one of the other surgical options or modifications should be considered if deemed appropriate. These alternate surgical techniques and modifications often require a longer and steeper learning curve, and are frequently associated with longer cross-clamp times and increased blood loss during the operation (57-59). When using one of these options it is important to consider whether the benefits of avoiding prosthesis-patient mismatch outweighs the perceived risk and other drawbacks of using one of these techniques. One also has to consider that there are presently still limitations in determining the "critical" indexed EOA at which adverse events occur, and that there are also conflicting results when using these small valves. Furthermore, the actual sizer dimensions and tissue annulus

dimensions of these small aortic prostheses vary considerably from their marked manufacturers diameters, and these differences should also be considered to ensure optimal prosthesis selection for individual each patient (14,60).

The level of physical activity of the patient should also be considered, as an activity level acceptable for an older sedentary patient would not necessarily be adequate in a young active patient. Furthermore, mild degrees of prosthesis-patient mismatch may be acceptable when the surgical risk is high, whereas severe prosthesis-patient mismatch may not be acceptable in these higher risk patients.

Mechanical aortic valve replacement in the small aortic root:

Mechanical aortic valve replacement is today still predominantly utilized in most centers and cases, mainly due to the ease of their implantation, despite concerns about these mechanical valves having smaller orifices than those of the corresponding native valves and thus causing some degree of obstruction due to the sewing ring or mechanical valve components, which varies inversely with the valve diameter (1,61). In spite of the increasing age of the valve replacement population, and an overall worldwide trend towards inserting more bioprosthetic valves in these older patients, mechanical valves still make up about 60% of the heart valves implanted worldwide. However, the market division between mechanical and tissue valves varies widely among different countries (for example, mechanical valves constitute approximately 90% of the market in Japan but

only 10% of the market in Brazil) (62), but there are numerous other individual factors that enter the equation when deciding on which particular valve to use, and particularly relating to safe and effective anticoagulation which is required if a mechanical valve prosthesis is implanted.

Akins (62,63) reviewed the experience from the English-language literature for the 5 different brands of mechanical valves approved for implantation by the Food and Drug Administration (FDA) for implantation in the United States in 1991 and again in 1995. These reviews favored the long-term results of the Medtronic-Hall tilting disc, and St. Jude Medical bileaflet mechanical valves. There have been continued various modifications and improvements to the different commercial valves available and the specific implantation techniques as to attempt to optimize prosthetic valve function, hemodynamics, EOA and clinical results. The St. Jude Medical bileaflet valve (figure 1) and the Medtronic-Hall tilting disc valve (figure 2) are the valves most commonly used and researched, but there is no unanimity over the single best valve to utilize for aortic valve replacement in the face of a small aortic root.

Figure 1:

St. Jude Medical bileaflet aortic prosthesis:

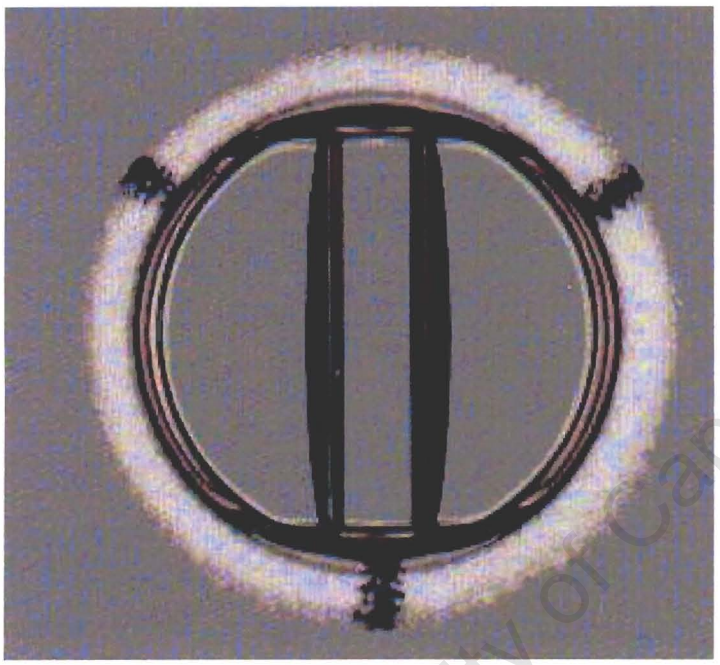
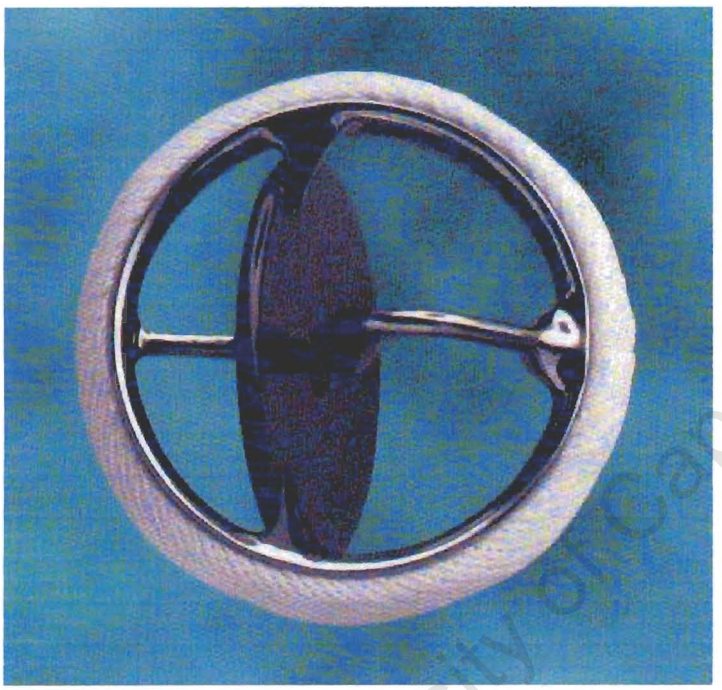


Figure 2:

Medtronic-Hall tilting disc aortic prosthesis:



Many studies and results favor either of these valves, whereas others do not detect any significant difference in the performance of the St. Jude Medical and Medtronic-Hall valves (64). All that is certain is that the performance of both the St. Jude Medical (5,65) and Medtronic-Hall (62,66-68) valves are apparently satisfactory in small aortic roots where a valve size of 21mm or less is used in the adult patient. Some studies suggest the Medtronic-Hall valve to be the mechanical valve of choice in the small aortic root (62,67,68), but these studies do not take into account the results of the new and improved

St. Jude Medical Valve with hemodynamic plus properties, for which there are no long-term results available as yet.

The orientation of mechanical aortic valve substitutes has to consider the eccentric blood flow patterns in the aortic root. The flow pattern at the level of the aortic valve is asymmetric with the highest flow velocities along the noncoronary leaflet with a counterclockwise rotation of 90° between commisures during systole, and the effect of valve orientation is a key marker for downstream turbulence and transvalvular energy loss. Laas et al (69) described how to optimize orientation of both tilting disc (Medtronic-Hall) and bileaflet (St. Jude Medical) mechanical valves. For the Medtronic-Hall valve, hemodynamic results close to normal physiology was obtained with the large orifice directed toward the noncoronary cusp, which is the area of major flow, and within a margin of 45° from this position to each side. In the bilaterally symmetric St. Jude Medical valve, the best results were found with one leaflet toward the right cusp. They found the Medtronic-Hall valve hemodynamic performance regarding turbulence and pressure gradients superior to the bileaflet valve design, and this difference is noted to be more pronounced the smaller the valve sizes.

Possible solutions to the problem of a small aortic root are to design a small prosthesis with better hemodynamics or to modify the sewing rings to make them smaller and more efficient, or to take advantage of supra-annular implantation.

Early experience with the new Masters Series of St. Jude Medical valve, which combine valve rotatability with the beneficial Hemodynamic Plus characteristics allowing for a larger valve orifice area for an equivalent tissue annulus diameter, and reducing the potential interferences of sub-annular tissue with leaflet mobility, demonstrate superior hemodynamic performance to standard size 21mm prosthetic aortic valves, and reduces prosthesis-patient mismatch and the need for aortic annulus enlargement (21,70).

The Carbomedics "Top-Hat" supra-annular prosthesis is a standard bileaflet valve in which the cuff has been transferred to the inflow level of the valve, with the prosthesis sitting above the annulus rather than within it, and the valve housing protruding into the aortic root like a top hat. Using this Carbomedics supra-annular prosthesis allows implantation of a larger prosthesis compared with standard Carbomedics prosthesis or other models, and this advantage is especially important in patients with a small aortic root (71,72).

Other surgical options and modifications in the small aortic root:

Table 1 shows the various surgical options and modifications available when replacing the aortic valve in the face of the small aortic root besides using mechanical aortic valve prostheses. As mentioned earlier, there is an overall and worldwide trend towards using more bioprosthetic valves. The use of standard intra-annular stented bioprosthetic valves < 21mm is generally avoided due to the belief that these small valves produce

unacceptably high postoperative gradients and almost certain prosthesis-patient mismatch. However, a recent study (even though a in small number of patients) showed significant reductions in left ventricular mass with acceptable gradients following implantation of small sizes (19–23mm) Carpentier-Edwards stented pericardial valves, and suggested that these stented pericardial valves can be used in the small aortic root without the need for aortic root enlargement procedures (73).

The dilemma of the obstructive small stented bioprosthetic valve has led to the design of supra-annular stented bioprosthetic valves like the Carpentier-Edwards supra-annular valve (26), and the advanced stent design of the Medtronic Mosaic and Hancock II valve with Supra X positioning allowing the sewing ring to sit above and outside the annulus, and allowing the opportunity to implant a larger valve size for an equivalent tissue annulus diameter.

Further techniques used to avoid mismatch and allow insertion of a mechanical or stented bioprosthetic prosthesis larger than the size of the native aortic root include: riding the prosthetic valve up above the native aortic valve annulus in the noncoronary sinus (partial supra-annular placement of the prosthesis) with the sewing ring on the annulus and below the coronary ostia in the left and right coronary sinuses (74), mechanical dilatation of the small aortic annulus (75), associated septal myectomy of hypertrophic septal myocardium as to enlarge the left ventricular outflow tract, and widening or enlargement of the aortic valve annulus and aortic root (Table 1).

These root widening procedures enlarge the native aortic valve annulus by cutting through and enlarging the native aortic valve annulus in various areas, and patching the left ventricular outflow tract and aortic valve annulus diameter as to allow placement of a larger sized valve prosthesis as to attempt to alleviate the problem of prosthesis-patient mismatch. There are various aortic valve annular and root widening procedures described all enlarging the aortic valve annulus to various degrees. In many instances, enlarging the aortic annulus as little as 2-3 mm will be sufficient.

The Nicks-Nunez root widening procedure is usually most frequently used. When employing this technique, the aortotomy incision is extended through the aortic valve annulus in the mid portion of the noncoronary sinus and carried into the fiberous trigone at the base of the anterior mitral leaflet, but not into or through the mitral valve annulus, until an acceptable diameter valve sizer can be passed. This incision is then patched using a broad-based patch (elliptical or teardrop shaped) of bovine or autologous pericardium, dacron or goretex. The prosthetic aortic valve is sewn to the native aortic valve annulus and to the patch in the area of the annular incision. The remainder of the patch is incorporated into the aortotomy closure and serves to facilitate aortotomy closure and to widen the supravalvular ascending aorta. The Nicks-Nunez aortic root widening procedure usually allows placement of a prosthetic valve at least one size larger as this procedure enlarges the aortic root approximately 2-4 mm, but in my opinion and experience, a well performed Nicks root widening procedure, can easily accommodate a prosthetic valve of two sizes larger.

The Rittenhause-Manougian aortic root widening procedure is used when a more extensive aortic root widening procedure is required. Here the aortotomy incision is extended between the left coronary and noncoronary commisure, and carried onto the fiberous trigone at the base of the anterior mitral leaflet, and may even extend into the base of the anterior mitral leaflet with care to make the incision precisely in the middle of the anterior mitral leaflet and to leave the free edge of the leaflet intact, and the left atrium which is entered at its attachment to the aortic root may be opened further to facilitate exposure. A diamond shaped patch is then used to reconstruct the V-shaped defect in the anterior mitral leaflet and aortic valve annulus, and the aortic prosthetic valve is sewn to the native annulus and patch in the area of the aortic annular incision. The left atrial roof incision is then closed by suturing it to the patch and valve sewing ring. The superior portion of the patch is incorporated into the aortotomy closure, which serves to facilitate the aortotomy closure and to widen the supravalvular ascending aorta. Neither the conduction tissue, nor the coronary arteries should be at risk, and concerns about postoperative mitral regurgitation due to anterior mitral leaflet distortion have apparently not proven significant, but a concomitant mitral valve replacement may well be required. This procedure usually enlarges the aortic valve annulus 3-5 mm, but the aortic valve annulus circumference may be enlarged from 10 to 25 mm using this technique, and usually allows placement of a valve 2-3 sizes larger. In addition, placement of an aortic valve homograft as a mini-root often allows significant enlargement of a narrowed aortic root using either a Nicks or Manougian incision, and an additional benefit when using a homograft is that the homograft anterior mitral leaflet can be used to patch the defect created by the root widening procedure.

The Konno-Rastan aortic root widening procedure or so-called aortoventriculoplasty is used rarely, but particularly in children with fibromuscular subaortic stenosis, or in cases where previous conservative aortic root widening procedures have been unsuccessful. The aortic valve annulus is enlarged from an anterior approach, and involves more complex reconstruction of the aortic outflow tract, ventricular septum and right ventricular outflow tract. A longitudinal or vertical anterior aortotomy incision is extended through the right coronary sinus through the aortic valve annulus 4-5 mm to the left of the right coronary ostium and down into the ventricular septum. The right ventricular outflow tract is similarly incised along the same line of orientation connecting with the aortotomy incision. The subaortic area and aortic valve annulus is widened by patching the ventricular septal incision using a diamond shaped patch, and placing the aortic valve prosthesis to the native aortic annulus and patch. The aortotomy is closed using the remainder of the diamond shaped patch. The right ventricular outflow tract incision is closed using a second patch secured to the inner patch over the aorta. This Konno-Rastan procedure provides the largest increase in aortic annulus size, and the annular diameter may be increased by up to 50%, enlarging the aortic valve annulus 5-8 mm, and allows placement of a valve 3-4 times larger.

These aortic root widening procedures are unfortunately not devoid from added operative risk (particularly in inexperienced hands), and may considerably lengthen the time of myocardial ischeamia and the complexity of the procedure. The potential benefits of the procedure need to be weighed up against the potential risks when employing one of these root widening procedures as to allow insertion of a larger prosthesis and thus avoiding

prosthesis-patient mismatch (14,57,72,74). However, in experienced hands these aortic root widening procedures, and in particular the relatively simple Nicks-Nunez aortic root widening procedure, is a good adjunct to the management of the problem of prosthesis-patient mismatch, and in my opinion should be used far more often, as I do in my own practice.

The use of an aortico-apical conduit with placement of a valved conduit from the left ventricular apex to the descending thoracic aorta or abdominal aorta may be indicated in selected cases including: insurmountable calcification of the aortic root and ascending aorta (porcelain aorta), severe congenital aortic stenosis (ie. severe root hypoplasia), and multiple previous procedures rendering the aortic root and aortic valve annulus unapproachable.

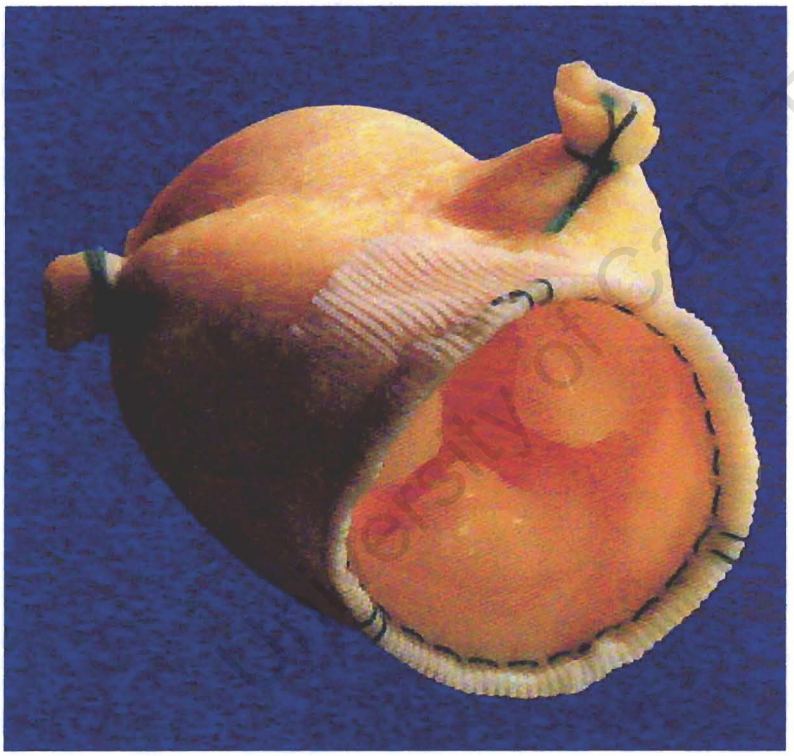
Aortic valve homografts are also appropriate for the small aortic root as the hemodynamics of this valve is excellent, and it is the ideal substitute in a small aortic root from a hemodynamic aspect, but their durability as well as their availability is limited (72,76).

The use of stentless bioprosthetic aortic valves is a newer alternative for dealing with the small aortic root, and is considered by many to be the valve of choice in the small aortic root, particularly in older patients, but there are many other specific indications for the use of these stentless valves. There are various different stentless aortic valves manufactured, of which the Medtronic Freestyle porcine (Figure 3), Biocor composite

pericardial, Prima Edwards and St. Jude Medical Toronto SPV stentless valves are the most popular.

Figure 3:

Medtronic Freestyle Stentless Aortic Valve Prosthesis:



These stentless valve prostheses generally have better hemodynamic performance than other replacement options, provide a larger indexed EOA, and a larger sized prosthesis can be inserted in an equivical smaller annulus, thus potentially avoiding the need for

aortic root widening procedures (23-25,77-81). These stentless valves show excellent hemodynamic performance due to their comparably large internal diameter and flexibility, and the valve can also be oversized in a controlled fashion without any additional complications, which is especially advantageous in patients with small aortic roots (82,83). However, the durability of these stentless valves are not yet known as with no long-term results yet available, there is a steeper learning curve with longer ischeamic times when implanting these valves, indications the for the use of this valve do not include the total population requiring aortic valve replacement, and some studies have shown conflicting evidence that stentless and stented valves have similar hemodynamic profiles in the small aortic root when matched on true measured internal diameters (84).

The clinical benefit of the stentless porcine valve may be due to patient selection or the lack of a rigid stent in the small aortic root, but is not due to hemodynamic superiority over stented aortic valves of similar sizes (84). Another attractive alternative is the use of a pulmonary autograft in the aortic position (Ross procedure), which provide an indexed EOA similar to that of the normal aortic valve (58,59,85), but again there is a learning curve, longer ischeamic times, and increased potential risks.

Aortic valve repair procedures is another attractive alternative, but the indications for selective leaflet decalcification and reconstruction in the face of aortic stenosis and the small aortic root are limited with increased potential risks and failure rates.

RESEARCH TEXT AND RESULTS:

Patients and Methods:

Patients

Between January 1996 to December 2000, 455 consecutive single aortic valve replacement procedures were performed at the University of Alberta Hospital, Edmonton, Canada, where I spent a year doing a Fellowship in Adult Cardiac and Transplantation Surgery. Table 3 shows the clinical characteristics of this single aortic valve replacement surgery patient population studied over this 5-year retrospective study period.

Acknowledgements:

The author would like to thank the University of Alberta Hospital and the Royal Alexandra Hospital Echocardiography laboratories, and the Edmonton Cardiology Consultants for their assistance in retrieval of data for this study, as well as Professor Arvind Koshal (Director of the Division of Cardiothoracic Surgery and Cardiovascular Research, University of Alberta Hospital, Edmonton, Alberta, Canada), and Professor Ulrich O von Oppel (Previous Head of the Department of Cardiothoracic Surgery, University of Cape Town, Cape Town, South Africa) for their guidance.

Table 3: Clinical characteristics of the patient population

Number of patients	455
Male gender	318 (69.89%)
Age (years)	57.91 ± 15.16
Aortic Valve Lesion	
Stenosis	140 (30.77%)
Regurgitation	120 (26.37%)
Mixed	195 (42.86%)
Etiology of Aortic Lesion	
Calcific degeneration	254 (55.82%)
Rheumatic	44 (9.67%)
Congenital	32 (7.03%)
Endocarditis	21 (4.62%)
Myxomatous degeneration	16 (3.52%)
Prosthetic valve	23 (5.05%)
Other	65 (14.29%)
Ejection Fraction (average)	
Poor (<30%)	27 (5.93%)
Moderate (30-50%)	185 (40.66%)
Good (>50%)	243 (53.41%)

Surgical Technique

Surgery was performed through a median sternotomy with near normothermic (34-36°C) cardiopulmonary bypass, using multi-dose cold 4:1 blood cardioplegia (5% Dextrose water with 100ml THAM, 22ml CPD and 40meq K (induction) or 10meq K (maintenance) added, delivered using the Sorin® blood cardioplegia delivery system), and intermittent topical cooling, with a terminal dose of warm blood cardioplegia as myocardial preservation. A transverse aortotomy was preferred by the surgeons in most of the cases. In aortic valve replacement cases the native valve tissue was excised, the annulus debrided, sized, and the appropriate prosthetic valve selected as per the size of the aortic valve annulus, but not related for BSA, patient size or activity level, and indexed EOA's were not considered as to attempt to alleviate postoperative prosthesis-patient mismatch. Stented Prosthetic Aortic Valves were inserted using inverting plegeletted mattress sutures. Postoperatively, patients received warfrin for anticoagulation if a mechanical valve prosthesis was used, in selected cases of bioprosthetic valve replacement, or if there was any other specific clinical indication for anticoagulation, most commonly the presence of atrial fibrillation. All other patients received anti-aggregatory asprin only, and specifically all the bioprosthetic stented and stentless valves which did not have a specific indication (like atrial fibrillation) for anticoagulation using warfrin.

Follow up

Patient data was collected retrospectively, and follow-up was obtained from clinical records, referring hospital and doctor records, and echocardiography laboratories where possible. Postoperative echocardiographic analysis included assessment of aortic prosthesis peak and mean gradients, aortic prosthetic valve hemodynamic function and left ventricular function. Prosthetic valve orifice areas were assessed by echocardiography in some cases (< 20% cases studied), but individual indexed EOA's were not assessed or considered either at the time of surgery or follow up. Patient mortality and morbidity are reported according to standardized published criteria (15, 16).

Statistics

Means or averages with standard deviations are provided where appropriate. Statistical comparisons were by Chi-square (Epi Info version 6, Stone Mountain, GA), linear regression (Summit Medical Systems In. Minnetonka, MN), or by two-tailed independent t-tests as indicated. A p-value of 0.05 or less was considered to be statistically significant.

Results:

Patient Characteristics

Preoperative patient characteristics are shown in Table 3. The average patient age was 57.91 ± 15.16 years with an age range of 17.27 – 85.94 years. The patients were predominantly of male gender, with the males making up 69.89% of the patient population.

The majority (42.86%) of patients presented with mixed aortic valve lesions (aortic stenosis and ≥ moderate aortic regurgitation), whereas in 30.77% the aortic valve lesions were predominantly stenotic in nature, and in 26.37% predominantly regurgitant in nature on preoperative echocardiographic, cardiac catheterization and clinical assessment. The predominant aortic valve lesion etiology was calcific degeneration (55.82%), with rheumatic heart disease as the etiology in only 9.67% of cases which is typical for a first world country, and very different from which we see in South Africa. Bacterial endocarditis was the etiologic culprit in only 4.62% of cases.

Regarding the average LV ejection fraction, 53.41% of cases were classed as being of good ventricular function (LVEF > 50%), and only 5.93% of cases were classed as being of poor ventricular function (LVEF < 30%), with the rest classed as being of moderate left ventricular function.

Operative data of the patient population is shown in Table 4. Of the 455 single aortic valve procedures performed over this 5 year period, 48 (10.55%) were re-operative procedures, 415 (91.21%) were aortic valve replacement procedures, and 40 (8.79%) were aortic valve repair or resuspension procedures. Of the aortic valve replacement procedures, 264 (58.02%) were mechanical aortic valves, 91 (20%) stented bioprosthetic aortic valves, 53 (11.65%) stentless bioprosthetic aortic valves, 4 (0.88%) pulmonary autograft valves (Ross procedures), and only 3 (0.66%) homograft valves.

Mechanical aortic valves used included 240 (90.91%, and 52.75% of total patient population) St. Jude bileaflet valves, and 24 (9.1%) Carbomedics bileaflet valves. The 91 stented bioprosthetic aortic valves used were of 6 different types, but predominantly Carpentier-Edwards Pericardial or Perimount (52 (57.14%)) and Carpentier-Edwards Porcine (18 (19.78%)) valves.

Amazingly, not even one single aortic root widening procedure was performed in any of these single aortic valve replacement procedures at this particular institution during the specified study period. Not employing these root widening procedures was the choice and prerogative of the specific group of surgeons in Edmonton, as they were of the opinion that employing these aortic root widening procedures significantly increased the risk of the procedure, as opposed to inserting a smaller sized prosthesis and risking prosthesis-patient mismatch, which is a view not shared by many surgeons around the world.

The choice of a specific valve used and procedure was dictated by specific patient factors including patient age, aortic valve lesion etiology, the need for and safety of full anticoagulation, specific patient preference, and personal surgeon preference and experience.

Table 4: Operative data of the patient population

Aortic valve replacement	**Mechanical Valves**	**Stented Bioprosthetic**	**Stentless Bioprosthetic**
Number	264 (58.02%)	91 (20%)	53 (11.65%)
Size of prosthesis implanted			
19 mm	20 (7.58%)	9 (9.89%)	0
21 mm	40 (15.15%)	23 (25.27%)	5 (9.43%)
23 mm	71 (26.89%)	27 (29.67%)	5 (9.43%)
25 mm	66 (25%)	20 (21.98%)	15 (28.3%)
27 mm	46 (17.42%)	5 (5.49%)	13 (24.53%)
29 mm	21 (7.95%)	7 (7.69%)	15 (28.3%)
Cross clamp time (min)	78.23 ± 30.22	77.57 ± 23.45	119.94 ±19.06
Body surface area (m^2)	2.03 ± 0.25	1.91 ± 0.28	1.98 ± 0.24

Early Mortality

The overall operative (in-hospital or 30 day) mortality was 3.52% (n=16). 12 of these early deaths occurred in the mechanical valve group (4.55%), whereas only one occurred in the stentless bioprosthetic group (1.89%). There were no early deaths in the stented bioprosthetic group. Of the 12 early deaths occurring in the mechanical valve group, only 2 were in cases receiving valve sizes ≤ 21mm, but this was not found to be statistically significant. There were no specific identified risk factors for early mortality in this group of patients. Age, gender, preoperative poor ejection fraction, bacterial endocarditis, re-operative surgery, operative status, disease etiology, and cross-clamp times were not predictive of operative mortality.

Follow up data

Postoperative data of the patient population is shown in Table 5. Both peak and mean postoperative aortic prosthetic valve gradients were assessed by echocardiography following discharge between 2 and 6 months postoperatively in 64% of cases, which was spread evenly across the patient population. As stated earlier, prosthetic valve orifice areas were only assessed in some cases (< 20% cases). Individual indexed EOA's were also not assessed or considered by this group. The average postoperative aortic prosthetic valve peak and mean gradients assessed by transthoracic echocardiography for the different types and sizes of valves are shown in Table 5.

Table 5: Postoperative data of the patient population

Aortic valve replacement	Mechanical Valves	Stented Bioprosthetic	Stentless Bioprosthetic
Number	155 (252)	50 (91)	50 (52)
Peak prosthetic valve gradients			
Prosthesis size			
19 mm	27.71 ± (10.80)	26.50 ± (10.54)	0
21 mm	24.38 ± (11.38)	30.29 ± (11.67)	27.60 ± (10.06)
23 mm	25.38 ± (12.69)	32.55 ± (11.88)	17.25 ± (6.70)
25 mm	24.20 ± (10.64)	22.85 ± (6.90)	19.67 ± (7.60)
27 mm	18.96 ± (11.10)	21.50 ± (2.12)	18.73 ± (2.97)
29 mm	15.63 ± (4.47)	25.75 ± (8.46)	17.93 ± (6.28)
Mean prosthetic valve gradients			
Prosthesis size			
19 mm	15.71 ± (5.89)	13.50 ± (4.85)	0
21 mm	13.25 ± (7.05)	15.93 ± (6.90)	14.60 ± (5.37)
23 mm	13.47 ± (6.17)	19.09 ± (9.76)	8.75 ± (2.87)
25 mm	12.80 ± (5.26)	13.00 ± (3.24)	10.73 ± (4.51)
27 mm	10.21 ± (5.87)	10.00 ± (1.41)	10.09 ± (1.97)
29 mm	8.81 ± (2.66)	15.50 ± (6.45)	9.60 ± (3.02)
Early Mortality	12 (4.55%)	0	1 (1.89%)

These early peak and mean postoperative aortic prosthetic valve gradient values were used to assess whether there was any statistically significant difference in the University of Alberta Hospital experience between the different sizes and types of valves, and in particular the smaller and mechanical valves.

When comparing the mechanical aortic valve gradients, no statistically significant difference in early postoperative gradients was found between the 19mm and 21mm sized valves, between the 19mm and 21&23mm sized valves, between the ≤ 21mm and 23&25mm sized valves, or between the ≤ 21mm and ≥ 23mm sized valves (Table 6 & Figure 4).

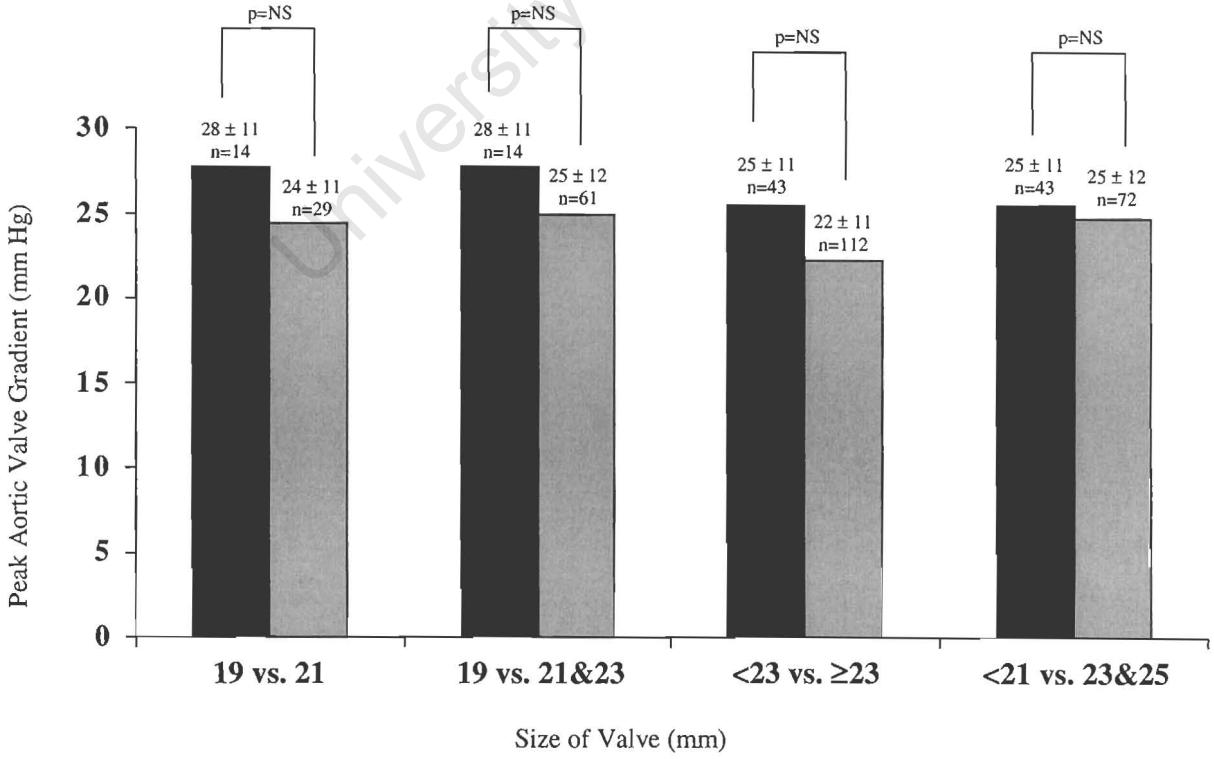
Table 6: Comparison of mechanical valve gradients

Valve sizes	Mechanical Valve Peak Gradients
19mm vs 21mm	27.71 ± 10.8 (n=14) vs 24.38 ± 11.38 (n=29), t_{41}=0.915, p=0.365
19mm vs 21&23mm	27.71 ± 10.80 (n=14) vs 24.90 ± 12.00 (n=61), t_{73}=0.805, p=0.423
≤ 21mm vs 23&25mm	25.47 ± 11.18 (n=43) vs 24.72 ± 11.53 (n=72), t_{113}=0.338, p=0.736
≤ 21mm vs ≥ 23mm	25.47 ± 11.18 (n=43) vs 22.19 ± 11.22 (n=112), t_{153}=1.63, p=0.105

Valve sizes	Mechanical Valve Mean Gradients
19mm vs 21mm	15.71 ± 5.89 (n=14) vs 13.25 ± 7.05 (n=28), t_{40}=1.13, p=0.267
19mm vs 21&23mm	15.71 ± 5.89 (n=14) vs 13.37 ± 6.54 (n=60), t_{72}=1.23, p=0.223
≤ 21mm vs 23&25mm	14.07 ± 6.72 (n=43) vs 13.10 ± 5.65 (n=72), t_{112}=0.828, p=0.41
≤ 21mm vs ≥ 23mm	14.07 ± 6.72 (n=43) vs 11.87 ± 5.61 (n=112), t_{152}=1.97, p=0.051

Figure 4:

Figure 4: Comparison of Peak Aortic Valve Gradients for Various Sized Mechanical Valves



When comparing the stented bioprosthetic valve gradients, again no statistically significant difference in early postoperative gradients was found between the 19mm and 21mm sized valves, between the 19mm and 21&23mm sized valves, between the ≤ 21mm and 23&25mm sized valves, or between the ≤ 21mm and ≥ 23mm sized valves (Table 7 & Figure 5).

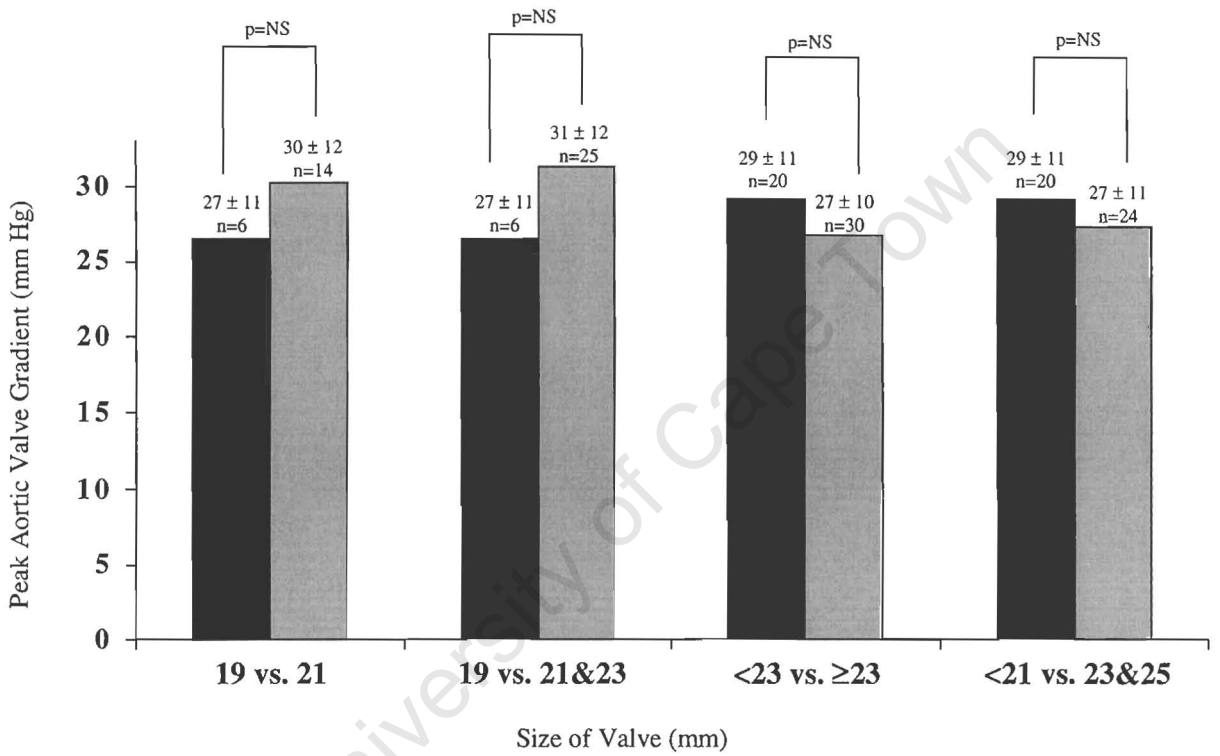
Table 7: Comparison of stented bioprosthetic valve gradients

Valve sizes	Stented Valve Peak Gradients
19mm vs 21mm	26.50 ± 10.54 (n=6) vs 30.29 ± 11.67 (n=14), t_{18}=0.683, p=0.503
19mm vs 21&23mm	26.50 ± 10.54 (n=6) vs 31.28 ± 11.57 (n=25), t_{29}=0.923, p=0.364
≤ 21mm vs 23&25mm	29.15 ± 11.2 (n=20) vs 27.29 ± 10.52 (n=24), t_{42}=0.567, p=0.574
≤ 21mm vs ≥ 23mm	29.15 ± 11.2 (n=20) vs 26.70 ± 9.88 (n=30), t_{48}=0.814, p=0.419

Valve sizes	Stented Valve Mean Gradients
19mm vs 21mm	13.5 ± 4.85 (n=6) vs 15.93 ± 6.9 (n=14), t_{18}=0.778, p=0.447
19mm vs 21&23mm	13.5 ± 4.85 (n=6) vs 17.32 ± 8.25 (n=25), t_{29}=1.08, p=0.288
≤ 21mm vs 23&25mm	15.2 ± 6.33 (n=20) vs 15.79 ± 7.52 (n=24), t_{42}=0.279, p=0.782
≤ 21mm vs ≥ 23mm	15.2 ± 6.33 (n=20) vs 15.37 ± 7.17 (n=30), t_{48}=0.084, p=0.933

Figure 5:

Figure 5: Comparison of Peak Aortic Valve Gradients for Various Sized Stented Valves*



When comparing the stentless valve gradients, the t and p-values approached statistically significant difference for the 21mm and 23&25mm sized stentless valves. However, for the 21mm and ≥ 23mm sized stentless valves there was a definite statistically significant difference for both peak (27.60 ± 10.07 (n=5) vs 18.64 ± 6.06 (n=45) respectively, t_{48}=2.93, p=0.005) and mean gradients (14.60 ± 5.37 (n=5) vs 10.02 ± 3.35 (n=45)

respectively, t_{48}=2.73, p=0.009), but as only 5 of the 53 stentless valves implanted were sized ≤ 21mm this may not be very accurate (Table 8 & Figure 6).

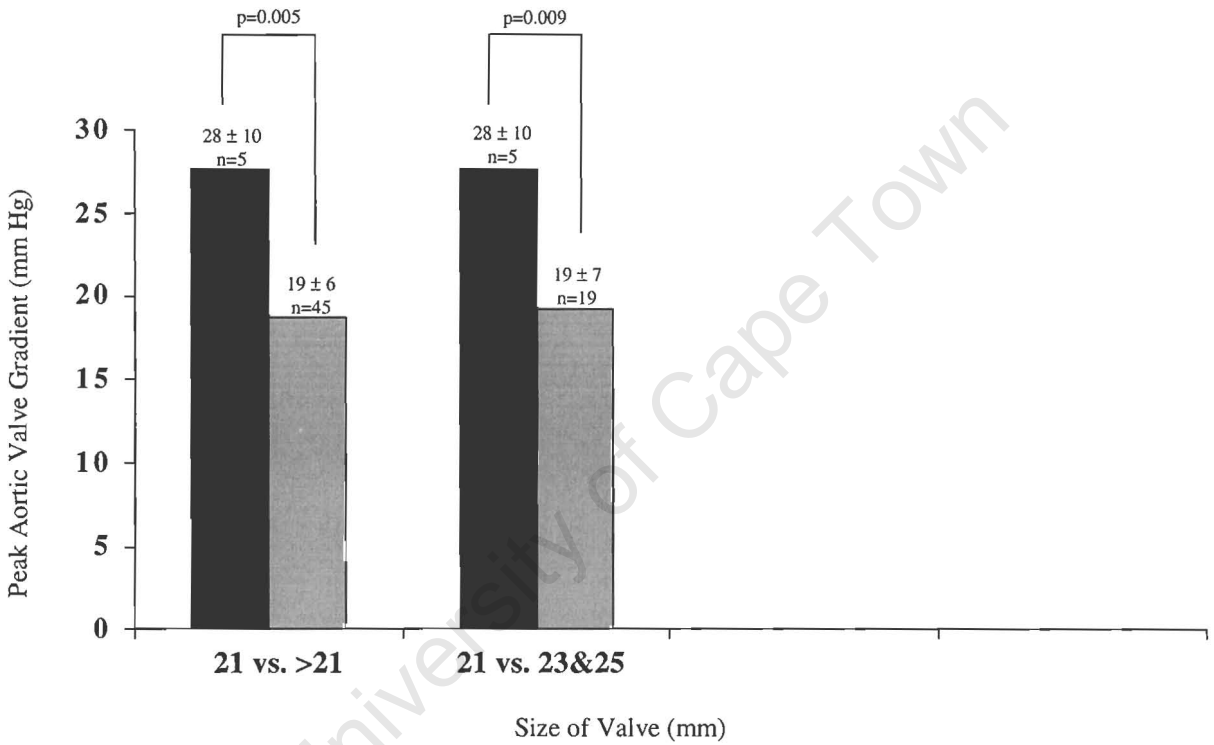
Table 8: Comparison of stentless bioprosthetic valve gradients

Valve sizes	Stentless Valve Peak Gradients
21mm vs 23&25mm	27.6 ± 10.07 (n=5) vs 19.16 ± 7.31 (n=19), t_{22}=1.95, p=0.055
21mm vs ≥ 23mm	27.6 ± 10.07 (n=5) vs 18.64 ± 6.06 (n=45), t_{48}=2.93, p=0.005

Valve sizes	Stentless Valve Mean Gradients
21mm vs 23&25mm	14.6 ± 5.37 (n=5) vs 10.32 ± 4.23 (n=19), t_{22}=1.91, p=0.069
21mm vs ≥ 23mm	14.6 ± 5.37 (n=5) vs 10.02 ± 3.35 (n=45), t_{48}=2.73, p=0.009

Figure 6:

Figure 6: Comparison of Peak Aortic Valve Gradients for Various Sized Stentless Valves



Again no statistically significant difference in early postoperative gradients was found when comparing mechanical and stented bioprosthetic valves sized ≤ 21mm for both peak (25.47 ± 11.18 (n=43) vs 29.15 ± 11.2 (n=20) respectively, t_{61}=1.22, p=0.228), and mean gradients (14.07 ± 6.72 (n=42) vs 15.2 ± 6.33 (n=20) respectively, t_{60}=0.63, p=0.232). Mechanical and stented bioprosthetic valves were not compared to the stentless bioprosthetic valves according to exact valve size as the use of a stentless valve

allows for insertion of a larger sized valve for an equivocal aortic valve annulus size due to a smaller sewing ring.

Therefore, in the University of Alberta Hospital experience, no statistically significant difference or any disadvantage was found to using small mechanical or bioprosthetic aortic valves as far as the early postoperative valve gradients (assessed 2-6 months postoperatively) are concerned, and this is why the University of Alberta Group feel it is appropriate to use these small mechanical and stented bioprosthetic valves in the face of the small aortic root, and not to employ aortic root widening procedures which they feel significantly increase the risk of the procedure, as opposed to inserting a smaller sized prosthesis and risking potential prosthesis-patient mismatch. The problem and shortfall with this approach is that it is based only on one postoperative variable, the early postoperative prosthetic aortic valve gradients, and do not assess or consider the postoperative prosthetic aortic valve gradients during exercise, the individual patient indexed EOA's, the direct impact of these small valves on long-term effort tolerance and exercise capacity, the regression of LV hypertrophy and the long-term survival of the patients who had these small prosthetic aortic valves implanted.

To further scrutinize the validity of the University of Alberta Group approach to the small aortic root and the implantation of these small prosthetic aortic valves, more of the aforementioned postoperative variables need to be assessed and considered, and in particular the long-term results which are unfortunately not available in this study which looks at early postoperative patient follow up only. The only other variable available for

scrutiny at this time, are the individual patient indexed EOA's, which are as mentioned before not considered at the time of surgery by the group in Edmonton. Referring back to the table compiled by Pibarot and Dumesnil (Table 2) which shows the determination of the minimal valve EOA required to ensure an indexed EOA of > 0.85 cm^2/m^2 (which is considered to be ideal) as to attempt to alleviate postoperative prosthesis-patient mismatch, I will more closely look at the particular group of patients in question, ie. those patients who have by definition have a small aortic root, ie. the group of patients in whom size 19 prosthetic aortic valves were implanted.

An indexed EOA of > 0.85 cm^2/m^2 is considered to be ideal, but an indexed EOA of < 0.60 cm^2/m^2 is considered to represent significant prosthetic aortic valve stenosis, prosthesis-patient mismatch, and have a significant negative impact on patient survival, although some studies have failed to demonstrate any significantly negative impact of prosthesis size and prosthesis-patient mismatch on short and medium-term survival of these patients following aortic valve replacement (4,51-55).

Tables 9 and 10 lists various variables pertinent for scrutiny in those patients with small aortic roots and having the smaller prosthetic aortic valves implanted. These variables include the EOA provided by the manufacturers, EOA determined by echocardiography postoperatively, patient BSA, preoperative left ventricular ejection fraction, the calculated indexed EOA (manufacturers EOA divided by patient BSA), and peak postoperative prosthetic aortic valve gradients. Unfortunately not all the values of echo

EOA, EF, and peak gradients are available for this group of patients, but the values available makes good sense and are significant when all the variables are compared.

In this group of smaller valves, a total of 20 size 19 mechanical aortic valves were implanted (Table 9). 19 of these valves were St Jude Medical Hemodynamic Plus valves (EOA 1.3 cm^2), and only one a Standard Carbomedics valve (EOA 1.1 cm^2). Body surface areas ranged from 1.241 to 2.092 m^2 and preoperative ejection fractions ranged from 37 to 64%. Postoperative EOA determined by echocardiography on follow up, was available in 7 of these patients, but compared well to the postoperative valve gradients, with the cases with smaller echo EOA's having much higher gradients. The valves with echo EOA's of 1.0 cm^2 had peak gradients of 30 and 50 respectively, and the valve with an echo EOA of 0.9 had a peak gradient of 46. The calculated indexed EOA's are of the most significance and interest. Only one (admittedly this was a very small patient with a BSA of only 1.241m^2) of these 20 patients had an indexed EOA of > 0.85 cm^2/m^2 which is considered to be ideal as to attempt to alleviate prosthesis patient mismatch, but on the bright side, none of these patients had indexed EOA's < 0.6 cm^2/m^2 which is considered to represent significant prosthetic aortic valve stenosis, but all of these valves fall in the "grey" zone as far as indexed EOA's are concerned, and all have the potential for prosthesis-patient mismatch, exercise intolerance and sub-optimal long term survival.

Table 9: Size 19 Mechanical Aortic Valves

Valve Type	EOA	Echo EOA	BSA	EF	Indexed EOA	Peak Gradient
Carbomedics	1.1	1.0	1.778		0.62	30
St Jude HP	1.3		1.241	45	1.05	
St Jude HP	1.3	1.4	1.546	60	0.84	21
St Jude HP	1.3		1.551	40	0.84	
St Jude HP	1.3		1.553	55	0.84	28
St Jude HP	1.3	1.3	1.559	45	0.84	11
St Jude HP	1.3		1.603	60	0.81	
St Jude HP	1.3		1.690	40	0.77	
St Jude HP	1.3	1.3	1.719	45	0.76	21
St Jude HP	1.3		1.746		0.74	
St Jude HP	1.3	0.9	1.752	64	0.74	46
St Jude HP	1.3	1.2	1.765	45	0.74	21
St Jude HP	1.3		1.792	55	0.73	
St Jude HP	1.3		1.920	60	0.68	28
St Jude HP	1.3		1.920	37	0.68	20
St Jude HP	1.3		1.963	60	0.66	34
St Jude HP	1.3		2.010		0.65	19
St Jude HP	1.3		2.044		0.64	36
St Jude HP	1.3		2.080	40	0.63	23
St Jude HP	1.3	1.0	2.092	55	0.62	50

A total of 9 size 19 stented bioprosthetic aortic valves were implanted (Table 10). All of these 9 valves were Carpentier Edwards Pericardial or Perimount valves (EOA 1.1 cm^2). Body surface areas ranged from 1.354 to 1.736 m^2 and preoperative ejection fractions ranged from 40 to 80%. Postoperative EOA determined by echocardiography on follow up, was available in 4 of these patients, but compared well to the postoperative valve gradients, with the cases with smaller echo EOA's having much higher gradients. The valve with an echo EOA of 0.9 cm^2 had a peak gradient of 46. The calculated indexed EOA's are of most significance and interest. Not one of these 9 patients had an indexed EOA of > 0.85 cm^2/m^2 which is considered to be ideal as to attempt to alleviate prosthesis patient mismatch, but on the bright side, again as in the case of the mechanical valves none of these patients had indexed EOA's < 0.6 cm^2/m^2 which is considered to represent significant prosthetic aortic valve stenosis.

Table 10: Size 19 Stented Bioprosthetic Aortic Valves

Valve Type	EOA	Echo EOA	BSA	EF	Indexed EOA	Peak Gradient
Perimount	1.1		1.354	40	0.81	
Perimount	1.1	0.9	1.453	50	0.76	46
Perimount	1.1		1.507	50	0.73	30
Perimount	1.1	1.1	1.526	56	0.72	22
Perimount	1.1	1.2	1.646	63	0.67	22
Perimount	1.1	1.2	1.674	80	0.66	23
Perimount	1.1		1.682	60	0.65	
Perimount	1.1		1.734	60	0.63	16
Perimount	1.1		1.736	72	0.63	

For the sake of completeness, indexed EOA's of the size 21 Medtronic Freestyle stentless valves should also be looked at and compared to the size 19 mechanical and stented bioprosthetic valves, as a stentless valve of one size larger is usually implanted for an equivalent aortic valve annulus. A total of 5 size 21 Medtronic Freestyle stentless valves were implanted (Table 11). Body surface areas ranged from 1.365 to 2.032 m^2 and preoperative ejection fractions ranged from 55 to 65%. Postoperative EOA determined by echocardiography on follow up, was available in only one of these patients, but unlike as in the case of the mechanical and stented bioprosthetic valves did not compare well to the postoperative valve gradient, but admittedly this is only one patient. The 3 patients

with larger body surface areas, had much higher peak gradients though, which is not unexpected and also seen in the other 2 groups. The calculated indexed EOA's are of most significance and interest. Only one of these 5 patients had an indexed EOA of > 0.85 cm^2/m^2 which is considered to be ideal as to attempt to alleviate prosthesis patient mismatch, but on the bright side, again as in the case of the mechanical and stented bioprosthetic valves, none of these patients had indexed EOA's < 0.6 cm^2/m^2 which is considered to represent significant prosthetic aortic valve stenosis.

Table 11: Size 21 Stentless Aortic Valves

Valve Type	EOA	Echo EOA	BSA	EF	Indexed EOA	Peak Gradient
Freestyle	1.35		1.365	55	0.99	18
Freestyle	1.35		1.754	60	0.78	17
Freestyle	1.35		1.803	65	0.75	28
Freestyle	1.35	1.6	1.950		0.69	36
Freestyle	1.35		2.032	60	0.66	39

Therefore, when considering the individual indexed EOA's of this group of patients who by definition have small aortic roots, almost all of these valves have indexed EOA's less than the value of 0.85 cm^2/m^2 which is considered to be ideal, and thus all of these small valves have the potential for significant prosthetic aortic valve stenosis, and the detrimental effects of prosthesis-patient mismatch, exercise intolerance and sub-optimal long term survival, which suggests that one should seriously reconsider the use of these

smaller valves, and certainly look towards the more liberal use of aortic root widening procedures or one of the other modifications.

CONCLUSIONS:

The surgical attitude and ideal approach towards the small aortic root and the concept of prosthesis-patient mismatch remains a topic of much controversy and intense surgical debate. Aortic prosthesis-patient mismatch when implanting small prosthetic aortic valves has long been believed to negatively impact on postoperative hemodynamic status, residual aortic stenosis, symptomatic improvement, regression of left ventricular hypertrophy, as well as long term results and survival. Mechanical aortic valve replacement is today still predominantly utilized by most in the small aortic root, and with good reason particularly with the continued advancements in valve design with superior hemodynamic properties, larger EOA's, and also supra-annular valve placement.

There are various attractive alternative surgical modifications available and used, all striving to alleviate or reduce prosthesis-patient mismatch with its proposed deleterious effects, and these modifications are very effective in individual experienced hands.

For optimal prosthetic valve performance at rest and exercise, and best results, the indexed EOA at rest should ideally be no less than 0.85-0.90 cm^2/m^2, but achievement of this goal must be dictated by personal and individual surgeon or group preference,

experience, results, and the anticipated and perceived added risks of these greater techniques and procedures which are associated with a longer and steeper learning curve, longer ischeamic times, and potential additional risks and complications for a given patient.

In the University of Alberta Hospital experience with short term follow up only, no statistically significant difference or any disadvantage was found to using these small mechanical or stented bioprosthetic aortic valves as far as early postoperative prosthetic aortic valve gradients (2-6 months postoperatively) are concerned. This is why the University of Alberta Group, and many surgeons around the world feel it is appropriate to use these small mechanical and stented bioprosthetic aortic valves in the face of the small aortic root, and not to employ aortic root widening procedures or some other greater procedure which they feel significantly increases the risk of the procedure, as opposed to inserting a smaller sized prosthesis and risking potential prosthesis-patient mismatch.

The problem and shortfall with this approach is that it is based only on one postoperative variable, the early postoperative prosthetic aortic valve gradients, and do not assess or consider the postoperative prosthetic aortic valve gradients during exercise, the individual patient indexed EOA's, the direct impact of these small valves on long-term effort tolerance and exercise capacity, the regression of LV hypertrophy and the long-term survival of the patients who had these small prosthetic aortic valves implanted. When further looking at the particular group of patients in question, ie. those patients who by definition have a small aortic root and had small prosthetic aortic valves implanted, and

considering the individual patient indexed EOA's, it is clear that almost all of these small valves are stenotic with the potential for prosthesis-patient mismatch.

Many surgeons around the world, including the University of Alberta Group, feel that a greater procedure when dealing with aortic valve surgery in the face of a small aortic root is not necessarily indicated for optimal results. However, postoperative prosthetic aortic valve stenosis and of prosthesis-patient mismatch with its potential deleterious effects, exercise intolerance and sub-optimal long term survival, is a very real problem, and I feel that in particular the simple Nicks-Nunez aortic root widening procedure should be used much more liberally as I do in my own practise. However, single every case should be individualized and scrutinized according to specific indications, surgical experience and results.

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