Trends in Aortic Valve Surgery in a Large Multi-Surgeon, Multi-Hospital Practice, 1979-1999

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Background and aim of the study: **Trends in aortic valve operations (AVO) may help to predict the future of aortic valve surgery in the context of changing case mix, population demographics, emerging technology and shifting paradigms.**
Methods: **All adults undergoing single AVO between 1979 and 1999 were reviewed retrospectively according to age, gender and other typical clinical variables, surgical complexity, specific operation and immediate outcome.**
Results: **There were 3,917 single AVO. Although coronary artery bypass (CAB) volumes declined by 15.3% between 1996 and 1999, AVO volumes have continued to increase by 11.7% since 1996. Over the entire period, there was no significant change in mean age or percent female gender, but increases in the prevalence of octogenarians and aortic stenosis were noted. During the 1990s, degenerative valve disease predominated and the prevalence of sicker patients according to heart failure class and surgical priority decreased. Trends in surgical complexity included an increase in AVO combined with CAB, but a stable 9:1 distribution of first operations to reoperations. Technology adoption included a decreased prevalence of mechanical valve use at the expense of increased use of tissue valves, especially stented xenografts and homografts. Transient technology adoption included stentless xenografts. Small numbers of pulmonary autografts, aortic valve repairs and valve-sparing aortic replacements were carried out. Predictors of hospital mortality rates for AVO included age 65 years, reoperation and combined AVO. Hospital mortality rates for AVO decreased for most age groups between the 1980s and 1990s, but not during the 1990s.**
Conclusion: **AVO volumes are steadily increasing, apparently as a result of the increase in octogenarians and the start of the 'baby boom' wave. Hospital mortality risk is related to age and surgical complexity, but is modest and has stabilized during the past decade. The prevalence of mechanical valve implants has decreased in favor of tissue valve replacement categories. The fastest growth rates have been with stented xenografts, and especially homografts. This may represent a paradigm shift away from mechanical solutions in favor of tissue solutions for aortic valve disease.**

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Recently, a reduction was experienced in the volume of cardiac surgical procedures, though this was due to a fall in the number of coronary artery bypass (CAB) operations rather than aortic valve operations (AVO). A recent analysis of population demographics has documented a contemporary increase in seniors, and especially octogenarians, due to a higher birth rate and immigration following World War I. Although the birth rate decreased after the Depression, it increased again dramatically after World War II. These population demographics have, therefore, predicted a dramatic increase in the prevalence of cardiac disease during the next three decades in the industrialized world as the large post-World War II 'baby boom' population subgroup begins to age (1). In light of these various forces, a retrospective review was undertaken of all adult AVO performed at the authors' institutions over the past 21 years in order to analyze current volume and procedure trends and immediate outcomes. A special interest was expressed in the adoption to changes in technology, and the paradigms underlying them. As the present authors constituted a large group

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of community-based cardiac surgeons working in four different cities, it was postulated that the results of this analysis might represent a preview of the future of aortic valve surgery in the developed world.

Clinical material and methods

Patient population

The authors' database registry was questioned for the time frame between January 1, 1979 and December 31, 1999 for all adult cardiac surgical patients. Demographics and typical preoperative, intraoperative and postoperative data variables were collected retrospectively and entered into a computerized Summit cardiac registry database. Data were downloaded from the registry and analyzed using Excel, Access and various statistical programs.

Definitions and abbreviations

Definitions of variables were consistent with those of the Society of Thoracic Surgeons (STS) National Cardiac Surgery Database. 'CAB' is a coronary artery bypass, while 'AVO' is any aortic valve operation with or without any other procedure, including CAB but not including another valve operation. Although the pulmonary autograft is a double valve operation, it is included in the single AVO analysis since the condition requiring surgery is a single valve problem. 'Isolated' is an AVO without CAB, while 'Combined' is an AVO with CAB. 'First op' is the initial operation of AVO, and 'Reop' is any reoperation of AVO. 'Simple' is a first op or isolated AVO, and 'Complex' is a reop or combined AVO. 'NYHA' is New York Heart Association heart failure symptom class; 'Elective' is a procedure that could be deferred without increased risk of compromised cardiac outcome, while 'Non-elective' is any operation not performed electively to include urgent, emergent and emergent-salvage categories. 'AR' is aortic valve regurgitation, 'AS' is aortic valve stenosis, and 'AVR' is aortic valve replacement. 'Tissue' specifically refers to an AVR, with material of biological origin, either autologous, homologous or heterologous; more broadly it also refers to aortic valve repair and aortic valve-sparing operations. 'Senior' refers to patients aged ≥65 years; 'Young senior' refers to patients aged 65-79 years; and 'Octogenarian' refers to patients aged 80 years or more. 'Hospital mortality' is death following surgery within 30 days of the operation or during the same hospitalization as the operation.

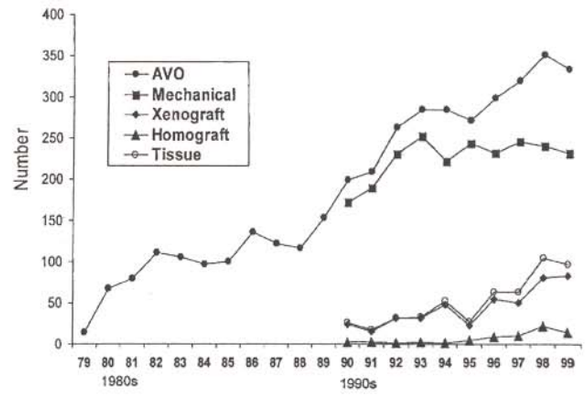

Figure 1: Aortic valve procedure volumes, 1979-1999. AVO: Aortic valve operation.

Statistical analysis

Data were summarized by frequencies and percentages for categorical factors and means and standard deviation for continuous factors. Various comparisons were performed using univariate analysis (chi-square, Fisher's Exact test) of categorical data. Fisher's Exact test was performed if the results of the chi-square test resulted in an expected value of less than 5. Univariate analyses of normally distributed continuous variables were carried out using Student's *t*-test. Variables were analyzed and significance was determined if the p-value was ≤0.05. P-values were the result of univariate analysis, unless otherwise stated; p-values >0.05 were designated as not significant (NS).

Multivariate analysis for predictors of hospital mortality was performed with 1990s data. The four possible binary risk factors analyzed were: time period of operation (1990-1995 versus 1996-1999); age (<65 versus 65 years); first operation versus reoperation; and isolated versus combined. In order to determine which

Table I: Opposite trends in coronary bypass and aortic valve procedure volumes, 1996-1999.

Procedure	Procedures performed (n)		Change (%)	p-value
	1996	1999		
CAB	1,895	1,605	-15.3	<0.001
AVO	299	334	+11.7	0.0371

AVO: Aortic valve operation; CAB: Coronary artery bypass.

Table II: Trends in clinical variables for aortic valve operations, 1979-1999.

Variable	1979-1995	1999	p-value
Age (years)*	64.6 ± 9.2[1]	65.8 ± 14.4	NS
Female gender (%)	36.7[1]	37.1	NS
NYHA class*	2.76 ± 0.87[2]	2.67 ± 0.99	NS
NYHA class I/I (%)	29.9[2]	44.9	<0.001
NYHA class III/IV (%)	70.1[2]	55.1	<0.001
Elective status (%)	93.8[2]	96.4	NS
Non-elective status (%)	6.2 [2]	3.6	NS

*Values are mean ± SD.
[1]Data for 1979; [2]data for 1995.
NS: Not significant.

variable or combination of variables were significantly associated with hospital mortality, a multiple logistic regression was performed using a stepwise process. For those variables remaining in the model, odds ratios (OR) and 95% confidence intervals (CI) were determined.

Results

Procedure volumes

AVO volumes increased in 14 out of 21 years since 1979 (Fig. 1). The continuing increase of 11.7% in AVO volumes since 1996, when CAB volumes reached a peak, is shown in Table I.

Patient demographics

Trends in clinical variables for AVO are shown in Table II. Between 1979 and 1999, there was a statistically non-significant increase in mean age and percent female gender. Between 1995 and 1999, when the data were complete, there was a decrease in the percentage of NYHA class III/IV patients, and a corresponding increase in the percentage of NYHA class I/II patients; the mean NYHA class showed a statistically non-significant downward trend. During the same interval, the prevalence of elective procedures showed a statistically non-significant upward trend, while the prevalence of non-elective procedures trended down, albeit non-significantly.

Between the 1980s and 1990s, the percentage of AR fell from 31.8% to 18.0%, the percentage of AS increased from 25.0% to 46.8%, and the percentage of AS/AR increased from 22.9% to 28.0%. In the second half of the 1990s, when complete data were available, the specific etiology of the aortic valve disease was: 64% calcific; 7.2% degenerative; 7.0% congenital; 5% rheumatic; and 2.3% endocarditis.

Trends in surgical complexity for AVO during the 1990s are shown in Table III. The ratio of first operations to reoperations remained virtually constant at 9:1, with no trend changes between the first and second halves of the decade. However, combined AVO increased from 44.2% to 53.9%, while isolated AVO decreased correspondingly, from 55.8% to 46.1%.

Trends in age group distribution for AVO are shown in Table IV. The <65-year age group decreased from 45.1% to 33.9% between the decades of the 1980s and 1990s, with no further decrease during the 1990s. The seniors increased from 54.9% to 66.1% between the 1980s and 1990s, with no further increase during the 1990s, while the octogenarians increased from 7.5% to 14.9% between the 1980s and 1990s, and showed an insignificant upward trend between 1995 and 2000. The young seniors increased from 47.4% to 51.2% between the 1980s and 1990s, but decreased insignificantly to 50.2% between 1995 and 2000.

Table III: Trends (% of procedures) in surgical complexity for aortic valve operations, 1990-1999.

Procedure	1990-1994	1995-1999	p-value
First operation	90.0	89.9	NS
Reoperation	10.0	10.1	NS
Isolated	55.8	46.1	<0.001
Combined	44.2	53.9	<0.001

NS: Not significant.

Technology adoption

Trends in technology adoption rates for AVO during the 1990s are shown in Table V. Mechanical valve implants decreased by 19.9% between 1990 and 1999, while stented xenografts increased by 101%. Stentless xenografts were first implanted in 1998, achieving 9.4% of AVO, and decreased to 0.6% in 1999. Homografts increased by 517% between the first and second halves of the decade. Pulmonary autografts were performed occasionally. The use of all tissue AVR (as a percentage of all AVO) more than doubled

Table IV: Trends in age group distribution (%) for aortic valve operations, 1979-1999.

Age group	Interval						
	1979	1979-99	1980-89	1990-99	1990-94	1995-99	1999
<65 years	50.0	37.1	45.1	33.9[1]	34.3	33.6	35.0
>65 years	50.0	62.9	54.9	66.1[1]	65.7	66.4	65.0
65-79 years	42.9	50.1	47.4	51.2[2]	52.5	50.2	52.1
80+ years	7.1	12.8	7.5	14.9[1]	13.2	16.2	12.9

[1]p <0.001, 1980-89 versus 1990-99; [2]p = 0.035, 1980-89 versus 1990-99.

between 1990 and 1999, from 13.1% to 29.0%.

In 1999, the prevalence of tissue valves and mechanical valves as a percentage of all AVO varied widely between surgeons and hospitals. Among the 14 surgeons with valve operations representing ≥10% of all their cardiac surgery, tissue valve percentages ranged from 5.3% to 76.9%, while corresponding mechanical valve percentages ranged from 94.7% to 19.2%. In five hospitals, tissue valve percentages ranged from 13.3% to 60.4%, while corresponding mechanical valve percentages ranged from 86.7% to 37.5%.

Hospital mortality

Predictors and trends of hospital mortality for AVO during the 1990s are shown in Tables VI-IX. The time period of operation, comparing the first and second halves of the 1990s, was not a predictor of mortality as determined by multivariate or univariate analysis. However, the time period of operation, when comparing the 1980s and 1990s, was a predictor of hospital mortality among certain age groups as determined by univariate analysis in Table IX.

Surgical complexity was a predictor of mortality for AVO, as shown by multivariate analysis in Table VI, and confirmed by univariate analysis. Reoperation was a predictor of mortality, with a 12.0% mortality rate - nearly triple that for first op AVO. Combined AVO was a predictor of hospital mortality, with a 7.1% mortality rate - more than double that for isolated AVO. There were no trend changes in mortality for these complex or simple AVO categories between the first and second halves of the 1990s by univariate analysis (Table VII).

The impact of age on hospital mortality rates for specific aortic valve operations during the 1990s is shown in Table VIII. Although age significantly impacted the mortality rates for simple operations, there was also an upward trend for complex operations. The range was 1.8% for young patients undergoing an isolated AVO and 12.3% for seniors undergoing a reop AVO.

An age of 65 years was a predictor of hospital mortality for AVO, as shown by multivariate analysis in Table VI, with a rate nearly double that of younger patients. The trends in hospital mortality rates by age

Table V: Trends in technology adoption rates (%) for aortic valve operations, 1990-1999.

Technology	Year (1990s)										Change (%)	p-value
	90	91	92	93	94	95	96	97	98	99		
Mechanical valve	86.4	90.4	87.5	88.4	77.6	89.3	77.6	76.6	68.2	69.2	-19.9	<0.001[1]
Stented xenograft	12.1	7.2	11.8	10.9	16.8	8.5	18.1	15.6	13.4	24.3	+101	<0.001[1]
Stentless xenograft	0	0	0	0	0	0	0	0	9.4	0.6	-93.6	<0.001[2]
Homograft	1.0	1.0	0.4	0.7	0.3	1.5	3.0	3.1	6.3	4.2	+517	<0.001[3]
Pulmonary autograft*	0	0	0	0	1.0	0	0	0.9	0.6	0	-	-
All tissue	13.1	8.1	12.2	11.6	18.2	9.9	21.1	19.6	29.5	29.0	+121	<0.001[1]

[1]90 versus 99; [2]98 versus 99; [3]90-94 versus 95-99.
*Three additional cases found on subsequent review were only included in the analysis of data in this table and not included in the AVO totals otherwise due to their minimal impact on data which had already been completely analyzed.

Table VI: Multivariate predictors of hospital mortality for aortic valve operations, 1990-1999.

Variable	Mortality (%)	OR	CI 95%	p-value
Age >65 years	6.0	1.8	1.2, 2.7	0.007
Age <65 years	3.1	-	-	-
Reoperation	12.0	3.3	2.2, 4.9	<0.001
First operation	4.3	-	-	-
Combined	7.1	2.3	1.6, 3.3	<0.001
Isolated	3.0	-	-	-

CI: Confidence interval; OR: Odds ratio.

group for AVO over various time periods by univariate analysis are shown in Table IX. For the entire study period, the overall mortality rates increased step-wise between the younger patients, young seniors and octogenarians, from 3.3% to 6.2% to 9.8%, respectively. For each age group, there was a decrease in mortality for all age groups between the decades of the 1980s and 1990s, achieving significance in the overall 65-year and 65-79-year age groups. During the 1990s there was a statistically non-significant downward trend in hospital mortality for the younger patients, and a statistically non-significant upward trend in hospital mortality for all the older age groups.

Discussion

Others have not consistently observed the absolute increase in the number of AVO observed in the present series. For example, it was not seen in the series from Emory University, 1988-1997 (2), although in reports from the Northern New England Cardiovascular Disease Study Group, 1992-1997 (3) and the UK Heart Valve Registry, 1988-1997 (4), an absolute increase in AVO was noted. The most obvious explanation for this probably lies in the changing population demographics of the industrialized world (1). The increase in the prevalence of seniors, and especially octogenarians, with their increased burden of degenerative aortic valve disease and the incoming wave of 'baby boomers' with their bicuspid aortic valve disease would easily account for the increase in AVO.

Although the Society for Thoracic Surgery (STS) recently developed a risk stratification model for cardiac valve replacement from the National Cardiac Surgery Database which identified similar risk factors for CAB (5,6), the software was not available at the time of analysis of the present data. However, the prevalence of the specific patient variables that were evaluated, and which contribute to a risk profile, were comparable with those detailed in other reports. Most other authors (2,3,5,7) have reported increasing age among AVO patients. The dilution of older patients with degenerative valve disease by much younger patients with bicuspid disease may account for the lack of significant age increase in the present overall AVO population. The absolute increase in octogenarians undergoing AVO has also been reported by others (8-10). Consistent with the present data, others (2,5) found no change in the prevalence of females at approximately one-third during the same time period. Although in the present study no increase was found in risk profile based on the variables evaluated, others (2,3) have reported an increased risk profile for their AVO patients. Regional differences in some components of the risk profile have also been reported. In the series of Northern New England (3), approximately 40% of the AVO patients were non-elective compared with only approximately 5% in the present series and in the series of Emory University (2). The prevalence of non-elective AVO in the most recent report from the

Table VII: Trends in hospital mortality rates (%) for aortic valve operation by surgical complexity, 1990-1999.

Procedure	1990-1994	1995-1999	p-value
Overall	4.4	5.5	NS
First operation	3.6	4.8	NS
Reoperation	12.1	11.9	NS
Isolated	3.2	2.9	NS
Combined	6.0	7.8	NS

NS: Not significant.

Table VIII: Impact of age on hospital mortality rates (%) for specific aortic valve operations, 1990-1999.

Procedure	Age		p-value
	<65 years	>65 years	
First operation	2.0	5.4	<0.001
Reoperation	11.6	12.3	NS
Isolated	1.8	4.0	0.01968
Combined	5.5	7.6	NS

NS: Not significant.

Table IX: Trends in hospital mortality rates (%) by age group for aortic valve operations, 1979-1999.

Age group	Interval years				
	1979-99	1980-89	1990-99	1990-94	1995-99
<65 years	3.3	3.7	3.1	3.3	3.0
>65 years	6.9	9.9	6.0[1]	5.0	6.8
65-79 years	6.2[2,3]	9.7	5.0[4,5]	4.0[6]	5.8[7]
80+ years	9.8	11.1	9.5	9.1	9.8

[1]p = 0.001, 1980-89 versus 1990-99; [2]p <0.001, versus <65, 1979-99; [3]p = 0.001, versus 80+, 1979-99; [4]p <0.001, 1980-89 versus 1990-99; [5]p <0.001, versus 80+, 1990-99; [6]p = 0.007, versus 80+, 1990-94; [7]p = 0.028, versus 80+, 1995-99.

STS National Cardiac Surgery Database (6) was approximately 20%.

Consistent with the present data, there appears to be a trend toward more surgical complexity for AVO. Others (2,5) have reported the trend toward more AVO combined with CAB with a similar relative prevalence of 40-50%. The Northern New England Study Group (3) also reported an increase in the prevalence of associated coronary artery disease in their AVO patients (from 52.5% to 59.8%) between 1992 and 1997. In the most recent STS report (6), 50% of all AVO were combined with CAB, nearly identical to the prevalence of combined AVO in the present series during the same time period. Contrary to the present data, others (2,3,5) - during the same time intervals - identified trends of increased percentage of reoperation for AVO, though with the same relative prevalence as in the present series of approximately 10-15%. The most recent report from the STS (6) and from the Cardiac Surgery Reporting System from New York State, 1994-1997 (11), reported a similar prevalence of reoperation for AVO of approximately 15% during the same time period.

The profile of aortic valve disease in the present patients was similar in other respects to other reported surgical series (12,13), in which stenosis pathophysiology dominates, and the relative frequencies of rheumatic and bicuspid disease have decreased while degenerative disease has increased. The association of similar risk factors for coronary artery disease and for degenerative aortic valve disease invites speculation that the natural history of the most common form of aortic disease may even be modifiable (14). If so, the prevalence of degenerative aortic valve disease could conceivably decrease in the future. The present authors have not seen any significant numbers of patients with prior diet drug exposure (15), suggesting that it will not be an important cause of aortic valve disease in the future. Although the prevalence of bicuspid valves in the population appears stable at approximately 2% (16), a better understanding of the frequent association of disease in the ascending aorta (16-18) may account for some of the continuing increase in patients referred for AVO. Additionally, the 'baby boomers', who are now in their 50s (1), are probably beginning to present with their bicuspid valve disease.

Although the classical indication for surgery for severe aortic stenosis has been the presence of symptoms (19), the recent ACC/AHA guidelines (20) have allowed some subsets of asymptomatic patients with severe aortic stenosis for surgical consideration. A recent study (21) has shown excess mortality with even NYHA class II symptoms and in asymptomatic patients with an ejection fraction <55% and indexed end-systolic diameter of 25 mm/m^2 body surface area (BSA). Evidence of increased operative mortality following aortic valve replacement in patients with increased left ventricular mass index further argues for earlier intervention, even in asymptomatic patients (22).

Excessive late mortality in women undergoing AVR for AR due to late aortic rupture (23,24) has prompted a recommendation for aortic replacement with indexed aortic diameters >2.4 cm/m^2 to account for smaller absolute aortic diameters in women (24). Since aortic dilatation has been the most common cause of AR during the past two decades (12), earlier treatment of both conditions will likely increase surgical referrals in the future. The increasing trend to refer asymptomatic AR patients with early left ventricular dysfunction will likely also increase surgical referrals in the future.

Mechanical valve implants continue to dominate in the present patients. Among the authors, the senior partner (D.M. Nicoloff) implanted the first St. Jude Medical mechanical valve in 1977 (25). This represented an important paradigm shift in favor of the bileaflet design, which continues today (26). However, there has been a near-20% decrease in mechanical valve implant rates over the past decade (Table V). The doubling of the stented xenograft implant rates and the five-fold increase in homograft implant rates resulted in a more than doubling of all tissue valve implants, despite the transient appearance of the stentless xenograft and the only occasional Ross procedure. The

increase in tissue implants at the expense of mechanical implants suggests the beginning of a paradigm shift away from mechanical solutions for valve disease in favor of tissue solutions.

The prevalence of mechanical valve prosthesis usage in other reports was generally in the same range as in the present series. Prevalence was 59.2% during 1991-1995 in the earlier STS study (5), approximately 70% in the UK Heart Valve Registry during 1990-1997 (4), and 80.0% in 1994 in the Nationwide Inpatient Sample report (27). In the earlier STS study (5), between the time intervals of 1986-1990 and 1991-1995, there was however a trend toward the use of more overall tissue valve replacements in AVO. Similarly, in the UK Heart Valve Registry report during 1990-1997 there was a steady trend towards use of the bioprosthesis at the expense of a mechanical valve (4). The prevalence of tissue valve usage in octogenarians was nearly 90% in several reports (8-10), even in overall series such as the UK Heart Valve Registry, where mechanical valves predominated (4).

The increase in stented xenograft implant rates in the present patients is likely due to several factors. There is a steady increase in the number of older patients as the population ages (1), consistent evidence that bioprosthetic durability increases with older age (28) and growing evidence for good surgical outcomes and reasonable five-year survival in the elderly, even with complex operations (8,9,29). From the patient's perspective, the lower bleeding rates of bioprostheses compared with mechanical prostheses, and the simplicity of 'no maintenance' may be more important than the risk of reoperation due to structural valve deterioration in their decision-making between valve choices (30).

Although the first aortic homograft was reported by Ross in 1962 (31), it was not widely available in the United States until 1994 when the FDA allowed its unrestricted use. During the latter half of the 1990s however, the aortic homograft has become an increasingly popular valve choice with the present authors, and has been especially popular among patients in their 50s and 60s, in those with combined aortic valve disease and aneurysmal disease of the ascending aorta, and also in those with an aortic root abscess resulting from either native or prosthetic valve endocarditis. Others (32) have also found the aortic homograft to be uniquely suited to complex native and prosthetic valve endocarditis.

Although Doty et al. (33) have consistently used the subcoronary implant technique in the United States, the present authors (34) have used the aortic root technique almost exclusively. The technical difficulty of these various aortic root procedures relates principally to achieving correct spatial orientation of the valve commissures and the coronary arteries. In the case of the present authors, it has seemed easier to establish the correct longitude and latitude of two coronary artery reimplantation sites than the correct three-dimensional relationship of three asymmetric valve commissures within variably shaped host roots. The root technique was popularized by O'Brien et al. (35) and Elkins' group (36) for predictable preservation of valve architecture. Others (37) have confirmed that the subcoronary implantation technique has a learning curve resulting in more initial aortic regurgitation and early reoperation compared with root replacement. Moreover, the root technique has been shown by Yacoub's group (38) to have an advantage in terms of both valve and patient survival over the subcoronary technique.

The appeal of the aortic homograft has been enhanced by the absence of any need for anticoagulants, a thromboembolic rate approaching that of the normal population (38,39), and normal hemodynamics during rest and exercise (40). Furthermore, there have been recent reports of >80% freedom from structural valve deterioration at 15 years in all age groups aged >20 years (39) and a low mortality risk at reoperation in experienced hands (41). The present authors (34) have expanded the use of the aortic homograft in patients with aortic annular dilatation, reasoning that the original annulus size was smaller and always consistently related to BSA (42). Based on principles of suture plication of the dilated mitral annulus and fixation of the corrected annulus dimension with an external restraining 'ring' as developed by Carpentier (43) in mitral repair operations, these same principles have simply been applied to the dilated aortic annulus. A reduction aortic annuloplasty is accomplished with individual sutures, and reinforced with an untreated autologous pericardial tube incorporated in the proximal graft suture line. Accordingly, during the past five years the present authors have not denied a homograft to any patient because of a dilated annulus, and have seldom implanted grafts larger than 22 mm diameter, even in large males.

The pulmonary autograft, which was first reported in 1967 by Ross (44), has been performed in only a small number of the present patients, despite its appeal as the ultimate 'stentless' valve. In fact, it has been considered the ideal aortic valve replacement device, easily fulfilling the objective performance criteria established for new prosthetic heart valves (45). It is characterized by normal hemodynamics at rest and exercise (46), and has excellent long-term function (47). However, the Ross procedure has not become a popular choice for aortic valve replacement in the authors' practice for a variety of reasons. A double valve operation for single valve disease has been a conceptual bar-

rier to adoption, especially by referring cardiologists. Moreover, the good long-term results with homografts in middle-aged patients (38,39), coupled with controversy over possible structural defects in the aortic and pulmonic wall in patients with bicuspid valves (17,48), have probably contributed to the relative lack of enthusiasm for the procedure.

A better understanding of the critical technical success factors employed by surgeons whose pulmonary autografts maintain stable dimensions and valve function over time (49,50) may encourage a more liberal application of the Ross procedure in the future. Recent reports of extremely low operative mortality rates of these more technically complex aortic root procedures may also serve to remove some of the existing bias against the pulmonary autograft, despite significantly longer cross-clamp and pump times (51).

The stentless xenograft, which became available commercially in the United States in late 1997, was met with early enthusiasm in the present authors' group in 1998, mainly due to its superior hemodynamics and purported survival advantage over stented xenografts (52). A similar trend toward an increasing prevalence of stentless xenograft usage from 1992 to 1994 followed by a plateau in usage at 3.0-4.0% from 1995 to 1997 was observed in the UK Heart Valve Registry report (4). The main reason for its near abandonment a year later in the present authors' group seems to be related to the additional complexity of subcoronary implantation resulting in a few early failures. Reports of late failures due to host root dilatation (53) may further discourage the use of stentless valves implanted by the subcoronary technique.

Additional controversy regarding prosthesis-patient mismatch and its questionable relationship to mortality (54) may have dissuaded some from bothering with a more complex operation, when a simpler implant with a stented xenograft would presumably provide the same survival result. Future data from ongoing prospective randomized trials between stentless xenografts, pulmonary autografts and homografts should help to clarify the appropriate niche for each procedure (51,55).

Although others have reported successful outcomes with aortic valve repair (56) and valve-sparing aortic replacements (57), the present authors' experience with these procedures was limited and not analyzed in this report due to small numbers. Aortic valve repair in this series has been confined to the occasional patient with a floppy bicuspid valve without significant pathology in the aortic root or ascending aorta. Valve-sparing replacements are currently reserved for young patients with aortic root aneurysms and normal leaflets or patients with aneurysms involving the tubular portion of the ascending aorta and the sinotubular junction.

Future developments in anticalcification treatment, collagen preservation and tissue engineering (58) may encourage even more use of tissue valves. If a durable, universally available tissue-engineered valve becomes available, then the need for homografts, autografts - and possibly even xenografts - may become obsolete. The future choice of appropriate valve implant techniques and valve-sparing procedures will be facilitated by the continuing investigation into the geometry (59), physiology (60), biomechanics (61) and microstructure (62) of the aortic root and leaflets. Such information should facilitate the development of techniques and technologies designed to minimize abnormal stresses on the leaflets in order to maximize valve durability.

Declining hospital mortality between the decades of the 1980s and 1990s has been reported by others (7), while stable hospital mortality rates during the 1990s have also been reported (2). Hospital mortality for AVO patients during the latter half of the 1990s was similar to that in other reports (2,3,6,11,13,27), where it was consistently about 6.0%. In the present study, no decline in hospital mortality was observed during the last decade as reported by others (3), most likely because mortality rates in the present study were lower to begin with and the improvements in myocardial protection had already been realized.

Others have also shown surgical complexity to be a risk factor for hospital mortality. The increased mortality with the addition of CAB to AVO in the present patients was also detailed in reports from the STS database (5,6), the Nationwide Inpatient Sample (27) and New York State series (11), with percentages similar to those in the present series at between 6.8% and 8.0%. Reoperation as a risk factor for mortality has also been reported by these same authors (5,6,11,27), with mortality rates similar to those of the present study. In light of this broad and consistent experience, it is important to note that surgical complexity by itself creates only modest risk and therefore should not be a contraindication to AVO in the future.

Age as a risk factor for hospital mortality after AVO has been reported by others (5,6,10,11,13,27). Moreover, there is a consistent stepwise increase in mortality between patients in their 60s, 70s and 80s. The hospital mortality rate of octogenarians undergoing AVO in the present series was similar to that in other series of patients between 1985 and 1995, with narrow ranges between 6.6% and 8.5% for AVO with and without CAB (5,8,9,63). As was noted with surgical complexity, age by itself creates only modest risk and, therefore, should not be a barrier to AVO in the future.

In conclusion, the continuing increase in patients needing AVO in the present group seems primarily to

be due to the rapid rise in the octogenarian population, with their progressive burden of degenerative (atherosclerotic?) aortic valve disease. Other probable reasons include the growing trend for surgical intervention in asymptomatic patients, and the incoming wave of 'baby boomers' with their bicuspid aortic valve disease. These population demographics in the developed world predict a continuing increase in patients needing AVO over the next three decades. Although hospital mortality rises with advancing age and surgical complexity, the increase has been only modest and is not likely to limit the current scope of AVO in the future. On the contrary, more complex and time-consuming operations will likely become more commonplace as worldwide experience with the more technically demanding aortic root procedures broadens. Despite the obvious influence of new technology on the application of specific surgical procedures, the adoption of technology has not been uniform in the present authors' group. However, a paradigm shift for AVO seems to be under way in favor of various tissue solutions rather than mechanical solutions for aortic valve disease.

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Meeting discussion

DR. RONALD ELKINS (Oklahoma City, Oklahoma, USA): Dr. Northrup, as an educator primarily, one thing I would like to know is when you have a transfer of practice among individual surgeons, do you look at the impact of the time of training on their practice patterns?

DR. WILLIAM F. NORTHRUP (Minneapolis, Minnesota, USA): I do not understand the question exactly.

DR. ELKINS: If you look at the time from completion of fellowship in thoracic surgery to joining your practice, do the surgeons' practice patterns differ from those of surgeons who have been in practice for 15 years? In your group, if somebody has been in practice for 10 years, then five years later is he doing something different, for example valve procedures or off-pump bypass?

DR. NORTHRUP: That is an excellent question, and it works both ways. When we have added new people to the group we have tried to obtain those who have adopted new technology - many of the off-pump coronary operations were performed by younger surgeons who already knew how to do such surgery. Some of the older surgeons have also adopted it, but as far as other procedures are concerned I don't think it necessarily relates to the time of training. It is more a function of ongoing education - developing an interest in valve repair, for example in the homograft or Ross procedure, and taking the time to learn how to do it. Our group seems representative of the spectrum - some people don't want to change and are happy to continue in their ways, but others are more adventurous. We have the whole spectrum, I think.

DR. ROBERT W. M. FRATER (Bronxville, New York, USA): I am not sure that your information can be extrapolated to the rest of the country, or to other countries in the world. You have a fairly special situation in Minneapolis. Certain surgeons in your group have a very high reputation in Minnesota for valve surgery, and I think what you are showing is that valve surgery automatically gravitates towards people who have shown the interest, energy and expertise in that field. So I don't think your statistics would be borne out in New York State where every single case is entered into a computer. I don't think we have seen the same trend. I think it is because you have some special guys in your group, and they are attracting patients and valve surgeons.

DR. NORTHRUP: That's an interesting point, and I didn't have time to develop all of these statistics in the short time we had - but we are working in five different hospitals in three cities, and in two of the cities we do virtually all of the cardiac surgery there. So we are not competing with other groups for cases. There is only one hospital where we compete with another group - and that's where the percentage of valves as a percentage of all of our cases is the highest. I agree with you - in one of our hospitals it is because of the surgeons' reputations, but at the other hospitals we do all the surgery in the community, and we haven't seen a problem. I think in that respect it may reflect the population at large, at least in those cities.

SIR MAGDI YACOUB (Harefield, UK): I congratulate you on a very thoughtful analysis of your practice - this acts as a model, and also the factors which influence it. Do you supplement that with a database to find out what happens to these patients to follow on from your excellent type of analysis?

DR. NORTHRUP: Yes, the database is very complete at the present time with regard to coronary bypass patients. It has been complete with the mechanical valve patients because of our tremendous interest over the years with mechanical valves. The mitral repair registry, which is a subset of our data, is evolving, and we are now starting a long-term follow up - and we will also continue that with the rest of the practice. We are in a state of evolution. As you know, the data business is very expensive, and sometimes we have to limit our spending in terms of data analysis. But it is an ongoing feature of our practice.