

# Fate of the Autograft and Homograft Following Ross Aortic Valve Replacement: Reoperative Frequency, Outcome, and Management

John W. Brown, Mark Ruzmetov, Toshihiro Fukui, Mark D. Rodefeld, Yousuf Mahomed, Mark W. Turrentine

Section of Cardiothoracic Surgery, James W. Riley Hospital for Children and Indiana University School of Medicine, Indianapolis, Indiana, USA

**Background and aim of the study:** The optimal hemodynamic performance and potential for growth of the pulmonary autograft has led to expanded indications for the Ross aortic valve replacement (AVR) procedure in some centers. The authors' institutional mid-term experience was reviewed to assess autograft and homograft hemodynamics, growth profile of the autograft, and reoperative frequency following Ross AVR.

**Methods:** Between June 1993 and June 2005, 167 consecutive patients (mean age  $24.9 \pm 15.5$  years; range: 1 month to 61 years) underwent Ross AVR: 48% of patients were aged <19 years. Additional procedures (n = 78) were performed in 55 patients (33%) at the time of the Ross procedure. In total, 151 patients had isolated aortic valve disease and 16 pediatric patients had more complex, multi-level left ventricular outflow tract obstruction.

**Results:** There were two early deaths (1.2%) and one late death (0.6%) over a mean follow up of  $5.1 \pm 3.0$  years (range: 1 month to 11 years). Actuarial survival at 10 years was 98%. In pediatric patients with Konno

procedure (n = 16), the pulmonary autograft mean annulus diameter increased from 10.2 to 19.9 mm. Twelve patients underwent 12 reoperations without mortality for autograft insufficiency or an ascending aortic aneurysm at a median interval of 5 years (range: 2 to 8 years): aortic annuloplasty and ascending aorta replacement (n = 4), composite aortic root replacement (n = 7), and repair of left ventricular pseudoaneurysm (n = 1). Freedom from replacement of the pulmonary autograft was 96% at 10 years. Five of the 164 surviving patients (3%) developed significant obstruction of the pulmonary homograft and required conduit replacement at a median of four years.

**Conclusion:** The Ross AVR can be performed with good mid-term results, including the pediatric age group. The potential for development of significant autograft insufficiency and homograft stenosis warrants annual follow up through the intermediate and late terms.

The Journal of Heart Valve Disease 2006;15:253-260

Aortic valve replacement (AVR) with a pulmonary autograft was first described in 1967 by Donald Ross (1). However, it was not until the past two decades that this procedure gained widespread acceptance, due in part to its excellent long-term durability (2). It has been shown, under both experimental and clinical conditions, that the pulmonary valve has a preserved growth potential, excellent resistance to infection, a low reoperative rate, and no need for anticoagulant

therapy. Hence, it is the aortic valve substitute of choice in children and young adults, as well as being a popular alternative for other patients who either refuse, or who have contraindications to, an anticoagulant regimen (3-8). For these reasons, the pulmonary autograft has become the present authors' valve of choice for children and young adults as well as selected older patients.

Critics of the Ross AVR argue against performing a two-valve replacement for one-valve disease, theoretically increasing the operative and reoperative risks in patients with isolated aortic valve disease. Reoperations for autograft regurgitation, ascending aortic dilation or homograft stenosis are uncommon, but are the most frequently cited reasons for reoperation in this patient population (9).

The study aim was to review the authors' institutional mid-term experience in order to assess autograft

---

Presented at the Third Biennial Meeting of the Society for Heart Valve Disease, 17th-20th June 2005, Vancouver Convention and Exhibition Centre, Vancouver, Canada

Address for correspondence:  
Dr. John W. Brown, Section of Cardiothoracic Surgery, Indiana University School of Medicine, 545 Barnhill Dr., EH 215, Indianapolis, IN, 46202-5123, USA  
e-mail: jobrown@iupui.edu

and homograft hemodynamics, the growth profile of the autograft, and reoperative frequency following Ross AVR.

## Clinical material and methods

### Patients

Between June 1993 and June 2005, 167 consecutive patients (114 males, 53 females; mean age  $24.9 \pm 15.5$  years; range: 1 month to 61 years) underwent Ross AVR at the Indiana University Hospitals, including the James W. Riley Hospital for Children in Indianapolis. Of these patients, six (4%) were aged <1 year, 75 (45%) were aged between 1 and 19 years, and 86 (51%) were aged >19 years. In total, 151 patients had isolated aortic valve disease, while 16 pediatric patients had more complex, multi-level left ventricular outflow tract obstruction (LVOTO). The indications for the Ross procedure are shown in Table I. A total of 109 previous cardiac operations or balloon procedures was performed in 74 patients (44%); surgical valvotomy and transventricular balloon valvuloplasty were the most frequent procedures performed before a Ross AVR. Fifty-two pediatric patients had undergone previous cardiac procedures (64%), while only 22 adults had prior aortic valve procedures (26%;  $p = 0.01$ ).

Seventy-eight additional procedures were performed in 55 patients (33%) at the time of the Ross AVR (Table II). The Ross operation was performed as an elective procedure in 152 patients (91%) and as an urgent/emergent procedure in 15 (9%). The latter group included 10 patients with acute bacterial endocarditis and five neonates and infants with critical aortic stenosis after failure of balloon valvuloplasty.

Hospital records were reviewed retrospectively, including operative records, as well as preoperative

and postoperative catheterization and echocardiography data. Transthoracic M-mode, two-dimensional, color-flow and Doppler echocardiograms were obtained in all patients before hospital discharge and annually thereafter. The degrees of autograft and neopulmonary regurgitation were quantitated as none/trivial, mild, moderate, and severe (10). Peak velocity flow across both semilunar valves was also assessed. In order to document growth of the pulmonary autograft in children, the early postoperative echocardiographic measurement of the diameter at the neo-aortic annulus was compared with the subsequent annular measurements.

### Surgical techniques

Standard techniques of cardiopulmonary bypass (CPB) were used, with bicaval cannulation, moderate hypothermia, and antegrade and retrograde cold blood potassium cardioplegia. A standard full-root technique was used for all Ross patients, as described previously (11). When a Ross-Konno procedure ( $n = 16$ ) was performed, the autograft was harvested with a 1- to 1.5-cm extension of attached right ventricular infundibular free wall muscle for use in patching the septoplasty incision. The right ventricular outflow tract (RVOT) was then reconstructed with an appropriately oversized (6-10 mm larger than the autograft) cryopreserved pulmonary homograft ( $n = 140$ ) or a decellularized pulmonary homograft (SynerGraft,  $n = 22$ ) (CrioLife, Inc., Marietta, GA, USA) or glutaraldehyde-preserved bovine jugular vein with integral venous valve (Contegra, Medtronic, Inc., Minneapolis, MN, USA;  $n = 5$ ). The patients were separated from CPB in the usual manner and intraoperative transesophageal echocardiography (TEE) was performed. Thirty-six patients had preoperative aortic annular

Table I: Indications for the Ross procedure.

Diagnosis	Patients (n)
Isolated aortic valve disease	151
AS + AI	107
AI	24
AS	20
Children with complex LVOTO	16
AS+SAS	6
AS+SVAS+SAS	5
AS+SVAS+SAS+CoA	2
Shone's anomaly	2
AS+SAS+IAA	1

AI: Aortic insufficiency; AS: Aortic stenosis; CoA: Aortic coarctation; IAA: Interrupted aortic arch; LVOTO: Left ventricular outflow tract obstruction; SAS: Subaortic stenosis; SVAS: Supravalvar aortic stenosis.

Table II: Concomitant procedures conducted in patients.

Procedure	Patients (n)
Konno	16
Reduction of aorta	30
Ascending aorta graft replacement	11
Subaortic membrane resection	10
VSD closure	3
CABG	3
Aortic arch patch augmentation	2
Mitral valve repair	2
Nicks' procedure	1
Total	78

CABG: Coronary artery bypass grafting; VSD: Ventricular septal defect.

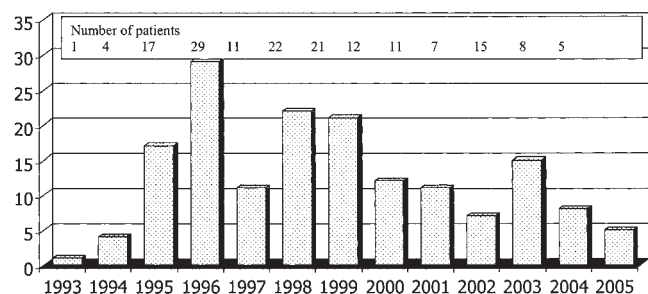


Figure 1: Distribution of all Ross procedures between 1993 and June 2005 at Indiana University.

dilatation and underwent reduction of the aortic annulus ( $n = 25$ ), ascending aorta replacement with synthetic graft ( $n = 6$ ), or ascending aorta reduction with subsequent replacement with a synthetic graft ( $n = 5$ ). The aortic annulus diameter was reduced, from  $30.1 \pm 3.8$  mm to  $24.7 \pm 2.2$  mm ( $p = 0.17$ ). The aortic annulus diameter in patients undergoing a Konno procedure was enlarged, from  $10.2 \pm 3.2$  mm to  $19.9 \pm 3.8$  mm ( $p = 0.05$ ).

### Statistical analysis

Results classified as “early” were those that occurred before hospital discharge or within 30 days of surgery if the patient was discharged from the hospital before 30 days. Statistical software (SPSS for Windows, version 10; SPSS Inc., Chicago, IL, USA) was used for data analysis. Actuarial survival and freedom from reoperation was determined using the Kaplan-Meier method. Data were expressed as mean  $\pm$  SD, or as median and range. For all tests, a  $p$ -value  $<0.05$  was considered to be statistically significant.

## Results

### Mortality and morbidity

Among patients there were two early deaths (1.2%) and one late death (0.6%). One 48-year-old patient with severe bicuspid aortic stenosis and micronodular cirrhosis with a history of hepatitis C underwent Ross AVR and coronary artery bypass grafting of the right coronary artery. Postoperatively, this patient had a cardiac arrest and died four days later from multisystem organ failure secondary to liver and pulmonary failure, hepatorenal syndrome and sepsis. One neonate with critical aortic stenosis underwent an emergent Ross-Konno procedure, aortic arch patch augmentation, and atrial and ventricular septal defect closure. This neonate required extracorporeal membrane oxygenation (ECMO) support and had an intracerebral bleed while being weaned from ECMO support five days postoperatively. One pediatric patient died six

months after a Ross-Konno procedure from aspiration pneumonia. Overall survival estimated by the Kaplan-Meier method, including early mortality, was 98% at one, five and 10 years.

Low cardiac output syndrome occurred in five patients (3%) postoperatively, and all five required ECMO; one of these patients died (early death described above). The second case occurred in a six-week old neonate with severe aortic insufficiency (AI) and an aortic valve mass. This pathology was felt to be due to an anticardiolipin antibody problem with calcified vegetations on the aortic valve. This patient could not be weaned from CPB following a Ross procedure and was placed on ECMO support. No recovery of ventricular function occurred over the next four days, and an orthotopic cardiac transplantation was performed on the fifth postoperative day. This child continues to do well eight years post-transplant. The other three patients were successfully weaned from ECMO and are long-term survivors. Additional morbidity included re-exploration for bleeding in one patient, and complete heart block requiring permanent pacemaker insertion in two patients (1%) (both had undergone a Ross-Konno procedure).

### Postoperative TEE

Postoperative TEE was performed routinely in the operating room after Ross AVR. No or trivial neo-aortic insufficiency was observed in 145 patients (87%), and 22 (13%) had mild AI. No patient had significant LVOTO. The valved conduit used to reconstruct the RVOT was competent in 148 patients (89%) and showed mild regurgitation in 19 (11%). No patient had important flow acceleration (obstruction) across the RVOT reconstruction.

### Follow up and NYHA functional class

Follow up was 100% complete. The mean follow up period was  $5.1 \pm 3.0$  years (median 5 years; range: 1 month to 12 years). In total, 143 patients (87%) were in NYHA functional class I and 21 (13%) in class II. Currently, all surviving patients are doing well and have not required anticoagulative cardiac medications after the third postoperative month.

### Pulmonary autograft failure

The most recent follow up echocardiogram revealed no/trivial AI in 142 patients (87%), mild AI in 20 (12%), and moderate AI in two (1%). The peak LVOT pressure gradient was  $16.9 \pm 11.4$  mmHg (range: 0 to 53 mmHg). Thirty-one patients (19%; 17 pediatric patients, 14 adults) had moderate aortic root dilatation ( $>40$  mm) which had occurred over a mean period of  $6.2 \pm 2.7$  years (range: 2 to 10 years). The actuarial freedom from pulmonary autograft failure (regurgitation grade  $>2+$ )

was 92% at five and 10 years.

Twelve patients underwent 12 reoperations for autograft insufficiency and/or ascending aortic dilatation at a median interval of six years (mean  $5.1 \pm 2.2$  years; range: 2 to 8 years). Autograft annuloplasty with resection of ascending aortic aneurysm was performed in four patients (2%), while redo aortic root replacement with a mechanical composite graft was performed in seven patients (4%). One patient underwent repair of a left ventricular pseudoaneurysm below the Ross valve. Freedom from replacement of the pulmonary autograft was 98% at five years, and 96% at 10 years.

### RVOT status

The most recent follow up echocardiogram revealed neopulmonary regurgitation as either none or trivial in 125 patients (76%), mild in 32 (20%), and moderate in seven (4%). The peak neopulmonary pressure gradient was  $22.5 \pm 10.5$  mmHg (range: 0 to 60 mmHg).

Five patients (3%) required reoperation for significant obstruction of the pulmonary homograft ( $n = 4$ ) or severe pulmonary regurgitation ( $n = 1$ ). The mean time period between the initial Ross procedure and RVOT reoperation was  $4.1 \pm 2.6$  years (range: 6 months to 7 years). Patients reoperated on for pulmonary homograft stenosis or regurgitation received a second standard pulmonary homograft implantation ( $n = 1$ ), a bovine pericardial valve ( $n = 1$ ), a decellularized pulmonary homograft (SynerGraft;  $n = 1$ ), or the RVOT was reconstructed with a Gore-Tex monocusp ( $n = 2$ ).

Two additional patients (one pediatric patient, one adult) developed a pulsed Doppler gradient of  $>50$  mmHg across the pulmonary homograft, and balloon intervention was planned. Five- and 10-year freedom from RVOT reintervention was 98% and 96%, respectively.

### Discussion

Today, the Ross AVR is considered to be a better alternative to mechanical, xenograft, and homograft AVR in the treatment of aortic valve disease, in both children and young adults (12-14). As in other centers, the present authors have expanded the indications for Ross AVR to patients with a more complex LVOT pathology, including active bacterial endocarditis, complex multi-level LVOTO, and patients with associated aneurysmal dilatation of the ascending aorta (3,15,16). Despite the inclusion of higher-risk patients, the procedure can be performed with a low overall mortality (1.2% for the present series). The frequency of Ross AVR at the authors' institution decreased over the latter half of the present experience, due mainly to the number of surgeons in the region offering Ross AVR. Before 2000, most Ross AVRs were performed by

two surgeons at the authors' institution, but since 2000 two other local institutions have offered - and are performing - the procedure in considerable numbers. This has resulted in a reduction in referrals to the present authors for Ross AVR. Recently, patient selection criteria have been broadened to include younger children and older adults aged over 55 years.

All three deaths in the present series (two early, one late) occurred in patients with complex associated problems. Both infants who died had undergone a Ross-Konno procedure, while the neonate who died early required additional procedures (atrial and ventricular septal defect closure, and patch aortoplasty). In neither case was death cardiac-related: one patient died from a central nervous system bleed while being successfully weaned from ECMO, while the infant who died late died from aspiration pneumonia. The Ross-Konno subgroup frequently presents in severe heart failure and has a higher expected mortality, there being no other attractive surgical options (15). The only adult death occurred in a patient who required coronary artery bypass and had advanced preoperative liver disease; this patient had a postoperative cardiac arrest and died from multi-system organ failure four days postoperatively. In the present study, survival for children and adults out to 11 years (mean 5.1 years) was 98% and compared favorably with the mortality of up to 5% reported in several other large series of children and adults (8,13,14,17,18).

In children and young adults who require AVR, the Ross procedure has now emerged as the operation of choice because it overcomes almost all of the limitations experienced with other types of AVR. The pulmonary autograft is virtually always available and it provides an autologous, viable tissue valve in the aortic position that maintains a potential for growth. Additionally, it provides freedom from most valve-related complications, including thromboembolism, and therefore obviates the need for long-term anticoagulation (3). The results of the present study showed that an excellent mid-term functional outcome can be achieved in most patients who undergo Ross AVR. More than 95% of the present patients had no or mild autograft regurgitation out to 12 years of follow up (mean 5.1 years).

Some centers have advocated the Ross procedure as the first procedure for LVOT obstruction in infants and children. In the experience of Lambert et al. (19), the only factors related to late mortality in Ross AVR were young age at the initial Ross operation, and the number of prior aortic operations. With the Ross procedure, the LVOT gradient is almost always completely eliminated and there is an expected regression of left ventricular mass (11), which should improve the long-term prognosis. The immediate surgical risk is

still higher for the Ross AVR in infants. The present authors and Van Son et al. (20) suggested that the first aortic valve procedure should be chosen according to the valvar anatomy, arguing in favor of valvuloplasty if the valve was trileaflet, but opting for insertion of the pulmonary autograft in the presence of a dysplastic bicuspid valve, after a failed surgical or balloon valvuloplasty.

Traditionally, children with complex LVOTO constitute a difficult group with a high incidence of residual and recurrent obstructive lesions (15,21). The present experience confirms that Ross AVR, when combined with a Konno ventriculoplasty, is an excellent therapeutic option for this complex subgroup. This procedure offers lasting relief of the LVOTO, with no Ross-Konno patient requiring reoperation for recurrent obstruction or regurgitation at mid-term.

Morbidity in the present series was low, with only one patient being returned to the operating room for postoperative bleeding. Heart block requiring a permanent pacemaker was required in two patients who had undergone multiple prior procedures and required a Ross-Konno procedure. Postoperative ECMO was required in five patients (3%); of these, three recovered uneventfully, one neonate patient required a heart transplant and survived, and one neonate had a cerebral hemorrhage as she was being successfully weaned from ECMO. These results compared favorably with those of other reports (8,13,14,18,22).

In the present authors' experience, pulmonary homograft regurgitation requiring replacement has been rare, with only one infant needing RVOT valve replacement. Homograft stenosis has been reported in a small percentage of patients (1-5%) in most large series (7-9,17), with infants having the highest rate of up to 25% at four years (16,19). To date, four (2%) of the present patients have required reoperation for homograft dysfunction. The primary reason for this low incidence of significant obstruction among homografts was the opportunity to oversize the homograft by as much as 10 mm in diameter. This oversizing offsets the expected shrinkage of the pulmonary homograft in most incidences. In the smallest infants, the present authors have, on occasion, elected to use a bovine jugular vein conduit, as this has not shown any tendency to shrink after implantation, and may also be more durable.

Autograft dilatation (>40 mm) following the Ross procedure has been demonstrated in several series (8,14,17,18,22,23), and occurred in 31 of the present patients, though only 11 (7%) developed more than mild regurgitation. In seven of these 11 patients the autograft was replaced with a composite conduit containing a mechanical valve. In the other four cases the

ascending aorta above the Ross valve was replaced with a Dacron graft and the Ross valve was preserved.

Patients who initially present for the Ross operation with a dilated ascending aorta (>35 mm) are at increased risk of developing an even larger ascending aorta (aneurysm) if the dilated ascending aorta is not resected and replaced at the time of the Ross AVR. Since 2001, the present authors have adopted the philosophy of replacing the dilated ascending aorta with an appropriately sized Dacron graft to support the sinotubular junction (STJ) of the autograft. They have also been more aggressive with regard to using a strip of Dacron fabric at the STJ of the autograft in adolescents and adults when the ascending aorta is not dilated but is larger than the autograft STJ. Reverting to a subcoronary or inclusion cylinder would not necessarily be useful in this subset. The Ungerleider technique (24) of placing a Dacron sleeve around the autograft was recently introduced to address this concern, but the present authors have not yet used this modification.

Annulus reduction and fixation should be considered in all older patients (aged >5 years) with predominant aortic insufficiency, and in any older patient who has an aortic annular diameter which is more than 2 mm larger than the pulmonary annulus diameter. Fixation at the STJ with a strip of Dacron is now routinely performed in older children and adults, but was not carried out routinely in the present series. During the past few years, the present authors have adopted Elkin's recommendation to replace the ascending aorta if it is significantly dilated (>35 mm). Systemic hypertension is also routinely treated postoperatively in an aggressive manner with beta-blockers and ACE inhibitors in order to prevent autograft dilatation and subsequent regurgitation.

Although the results of the present study were encouraging, the primary limitation was the lack of longer-term follow up. Follow up of the Ross patient must include regular echocardiographic evaluations of the pulmonary autograft. Autograft insufficiency is the most feared late postoperative complication in these patients, and it may develop late in follow up if systemic hypertension is not controlled from the outset (14,17,22). Progressive dilatation after the expected initial dilatation of the neo-aortic root and sinus diameters is uncommon (3,23). Elkins reported that there was evidence of dilatation of the aortic annulus after four years of follow up (17). Schoof et al. (25) performed an in-vivo study of the pulmonary autograft AVR in rapidly growing pigs, and found both growth and dilatation of the autograft root with preservation of the normal histologic characteristics of the pulmonary artery wall of the autograft. At the time of autopsy, the autograft valves were tested for insufficiency, but in-

vivo valve function was not determined. The Ross International Registry indicates that among 4,200 patients who were followed up, 83% were free of autograft explant at 21 years. Present clinical and experimental evidence does not fully answer the question of whether the pulmonary root will be a permanent AVR; however, failure rates have remained low and in most patients there has been minimal evidence of progressive dilatation. Continued close surveillance by routine annual echocardiography should form part of the evaluation of patients who have undergone a Ross procedure. Reoperative treatment of these patients should be based on ascending aortic dilatation, and autograft and homograft valve function. Patients with significant dilatation of the ascending aorta should be offered reoperation for ascending aortic replacement before the Ross valve develops moderate regurgitation.

The long-term function of right-sided pulmonary homografts in Ross patients is superior to their function as an extracardiac conduit used for congenital right heart defects. The use of alternatives to pulmonary homografts in the RVOT position in patients undergoing a Ross procedure has been attempted. The substitutes have included stented or stentless porcine valves, a Gore-Tex monocusp valve, and bovine jugular venous valve conduit. However, none of these materials has proven superior to the homograft, except in young infants where homograft durability is poor (personal experience).

The major contraindications to a Ross procedure are patients who have a genetic abnormality (e.g., Marfan syndrome) which affects the aortic valve and ascending aorta. Patients with a significant structural pulmonary valve abnormality should not undergo a Ross procedure. Based on the experience of other surgeons (17,18), patients with systemic lupus erythematosus, juvenile rheumatoid arthritis and other immune complex diseases should not undergo Ross AVR.

Mechanical and xenograft valve replacement in large series of adult patients has provided disappointing late results, with 12-year postoperative mortality rates of 50-60%, a reoperation rate of 30% for xenograft and 10% for mechanical valves at 12 years, and a combined thromboembolic and bleeding rate of 23% for xenografts and 45% for mechanical valves. The results outlined in the present report and in several other large series of Ross procedure compared favorably with the outcomes for mechanical and xenograft valves.

*In conclusion*, the Ross AVR is a versatile procedure that, with modifications (Konno), can be used for complex multi-level LVOTO in young infants and adults. Moreover, the results reported are superior to those

achieved with mechanical and xenograft valves because the Ross AVR eliminates most of the postoperative morbidity and mortality related to AVR. The potential for the development of significant autograft insufficiency, homograft stenosis and ascending aortic aneurysmal dilatation is small, but warrants annual follow up through the intermediate and late terms. Modifications to the original Ross AVR, including annular and sinotubular reduction and/or stabilization and concomitant replacement of the dilated ascending aorta, should further reduce the already low incidence of late Ross AVR postoperative problems. Oversizing the pulmonary homograft or sizing alternative right ventricular-pulmonary artery conduits may further reduce the low incidence of late RVOT problems seen with the Ross AVR. Further long-term follow up is required to determine the true durability of the Ross AVR over two to five decades.

#### References

1. Ross DN. Replacement of aortic and mitral valves with a pulmonary autograft. *Lancet* 1967;2:956-958
2. Ross DN, Jackson M, Davies J. The pulmonary autograft - a permanent aortic valve. *Eur J Cardiothorac Surg* 1992;6:113-116
3. Elkins RC, Knott-Craig CJ, Ward KE, McCue C, Lane MM. Pulmonary autograft in children: Realized growth potential. *Ann Thorac Surg* 1994;57:1387-1393
4. Niwaya K, Knott-Craig CJ, Santangelo K, Lane MM, Chandrasekaran K, Elkins RC. Advantage of autograft and homograft valve replacement for complex aortic valve endocarditis. *Ann Thorac Surg* 1999;67:1603-1608
5. Elkins RC, Lane MM, McCue C. Pulmonary autograft reoperation: Incidence and management. *Ann Thorac Surg* 1996;62:450-455
6. Sievers H, Dahmen G, Graf B, Stierle U, Ziegler A, Schmidtke C. Midterm results of the Ross procedure preserving the patient's aortic root. *Circulation* 2003;108:II-55-II-60
7. Forbess JM, Shah AS, St. Louis JD, Jaggars JJ, Ungerleider RM. Cryopreserved homografts in the pulmonary position: Determinants of durability. *Ann Thorac Surg* 2001;71:54-59
8. Fullerton DA, Fredericksen JW, Sundaresan RS, Horvath KA. The Ross procedure in adults: Intermediate-term results. *Ann Thorac Surg* 2003;76:471-477
9. Raanani E, Yau TM, David TE, Dellgren G, Sonnenberg BD, Omran A. Risk factors for late pulmonary homograft stenosis after the Ross procedure. *Ann Thorac Surg* 2000;70:1953-1957
10. Roman MJ, Devereux RB, Kramer-Fox R, O'Loughlin J, Spitzer M, Robins J. Two-dimension-

- al echocardiographic aortic root dimensions in normal children and adults. *Am J Cardiol* 1989;64:507-512
11. Brown JW, Ruzmetov M, Vijay P, et al. Clinical outcomes and indicators of normalization of left ventricular dimensions after Ross procedure in children. *Semin Thorac Cardiovasc Surg* 2001;13:28-34
  12. Turrentine MW, Ruzmetov M, Vijay P, Bills RG, Brown JW. Biological versus mechanical aortic valve replacement in children. *Ann Thorac Surg* 2001;71:S356-S360
  13. Elkins RC, Lane MM, McCue C. Ross operation in children: Late results. *J Heart Valve Dis* 2001;10:736-741
  14. Pessotto R, Wells WJ, Baker CJ, Luna C, Starnes VA. Midterm results of the Ross procedure. *Ann Thorac Surg* 2001;71:S336-S339
  15. Reddy VM, Rajasinghe HA, Teitel DF, Haas GS, Hanley FL. Aortoventriculoplasty with the pulmonary autograft: The "Ross-Konno" procedure. *J Thorac Cardiovasc Surg* 1996;111:158-167
  16. Marino BS, Wernovsky G, Rychik J, Bockoven JR, Godinez RI, Spray TL. Early results of the Ross procedure in simple and complex left heart disease. *Circulation* 1999;100:II-162-II-166
  17. Elkins RC. The Ross operation: A 12-year experience. *Ann Thorac Surg* 1999;68:S14-S18
  18. Corno AF, Goy J-J, Hurni M, Payot M, Sekarski N, von Segesser L. Treatment of congenital aortic valve stenosis: Impact of the Ross operation. *Swiss Med Wkly* 2001;131:65-69
  19. Lambert V, Obreja D, Losay J, et al. Long-term results after valvotomy for congenital aortic valvular stenosis in children. *Cardiol Young* 2000;10:590-596
  20. Van Son JAM, Reddy VM, Black MD, et al. Morphologic determinants favoring surgical aortic valvuloplasty versus pulmonary autograft aortic valve replacement in children. *J Thorac Cardiovasc Surg* 1996;111:1149-1157
  21. Starnes VA, Luciani GB, Wells JW, Allen RB, Lewis AB. Aortic root replacement with the pulmonary autograft in children with complex left heart obstruction. *Ann Thorac Surg* 1996;62:442-449
  22. Fullerton DA, Fredericksen JW, Sundaresan RS, Horvath KA. The Ross procedure in adults: Intermediate-term results. *Ann Thorac Surg* 2003;76:471-477
  23. David TE, Omran A, Ivanov J, et al. Dilatation of the pulmonary autograft after the Ross procedure. *J Thorac Cardiovasc Surg* 2000;119:210-220
  24. Slater M, Shen I, Welke K, Komanapalli C, Ungerleider R. Modification to the Ross procedure to prevent autograft dilatation. *Pediatr Card Surg*

Annual 2005;8:181-184.

25. Schoof PH, Hazekamp MG, van Wermskerken GK, et al. Disproportionate enlargement of the pulmonary autograft in the aortic position in the growing pigs. *J Thorac Cardiovasc Surg* 1998;115:1264-1272

## Meeting discussion

**DR. GIOVANNI LUCIANI** (Verona, Italy): I have three brief questions relating to your pediatric patients. First, did you perform the operation as a mini-root or inclusion cylinder in these patients, or just as a full root replacement?

**DR. JOHN W. BROWN** (Indianapolis, Indiana, USA): It was a full root replacement.

**DR. LUCIANI**: You would do that in a small infant with a complex LVOT?

**DR. BROWN**: We use the same technique in every patient - that has given us consistent results so far.

**DR. LUCIANI**: You mentioned oversizing the RVOT conduit, homograft, or whatever is used to repair the right side of the heart. Did you see any phenomenon of compression by the sternum in small infants or pediatric patients, and do you think that oversizing would cause problems in the pediatric population?

**DR. BROWN**: Based on our experience with homograft shrinkage, in the past five or six years we have tried to avoid using homografts, at least in very small infants. But in the first five or six years of the study homografts were all that was available. Even in a six-week-old child you may use a 10-mm autograft in the aortic position, but you can put a 16-mm pulmonary homograft in the right ventricular outflow tract. We are often limited by what is available, but we try to oversize as much as possible. Some authors have mentioned reducing an adult pulmonary homograft and making a bicuspid homograft with it, but we have avoided that as much as possible and try to use the largest homograft available. If I could find a valve that was 10-12 mm bigger than the one removed I would use it, because I would expect the homograft to shrink by at least 20%.

**DR. LUCIANI**: My final question relates to the mechanical valve population. You recently published data comparing the population and type of initial lesion results late after mechanical AVR in a pediatric population. So in a child, when would you advise using a mechanical valve and when would you use a Ross procedure?

**DR. BROWN**: In a child I would always use a Ross procedure. Our results with aortic or mechanical valves were pre-1993, when we began our Ross experience. Clearly, mechanical valves in children have performed reasonably well, but I would try to avoid

anticoagulation in children as much possible.

**SIR MAGDI YACOUB** (London, UK): I support the idea of placing the largest homograft in the right ventricular outflow tract, even in infants, because the homografts are in the right pleural cavity and it is easy to retain them. We also have placed an adult-size homograft in an infant aged about 3 months, and he has now reached 7 years with this 19 mm homograft with hardly any gradient. The idea that the graft will always calcify in an infant is not true, and to reduce the size seems counterproductive, because you need to place the biggest homograft possible in the right ventricular outflow tract.

**DR. ZOHAIR AL HALEES** (Riyadh, Saudi Arabia): Just to complicate things, a recent report from Europe maintains that oversizing actually does not prolong homograft life in the right ventricular outflow tract.

**DR. J. J. M. TAKKENBERG** (Rotterdam, Netherlands): Can you provide more detail about the nine reoperations on the autografts? This was for aortic regurgitation, but was there also dilatation? Also, how old were the patients? In our experience it is mainly adult patients who return for reoperation.

**DR. BROWN**: Only seven of our patients had to have their autograft explanted. Another five or six had the ascending aorta resected late postoperatively and an annuloplasty, but they continued to have their original

autograft. The age of patients who needed autograft explantation was distributed equally between teenagers and adults, who presented almost exclusively with primary aortic insufficiency and a dilated root. Generally we reinforced the annulus, but we did not always reinforce the sinotubular junction, and we did not resect the ascending aorta early on, as we do now routinely if it is dilated. So, answering your question, it was more the teenagers and adults who presented with pure aortic insufficiency and a dilated root and required late root replacement. We have used mechanical composite grafts in that group.

**DR. TAKKENBERG**: Can you suggest a reason why the infants are not coming back, but the adults are?

**DR. BROWN**: There are many possible explanations. First, the infant may have a slightly stronger autograft than the adult because it has been used at higher pressures in infancy and early childhood. There is often some pulmonary hypertension in those patients, and the pulmonary valves may in fact be better suited for the Ross procedure as some patients present in adulthood. It may well be that the autograft in a child is better than that in an adult. We do not have any strong data on this - it's just an impression. There may be slight differences in the disease process in adolescents and middle-aged adults but, again, that is just speculation.