

*Artículo especial*

## Results of aortic valve replacement with the pulmonary autograft-A critical appraisal of the Ross operation

Paul Simon<sup>1</sup>, Marie-Therese Kasimir<sup>1</sup>, Jyotindra Sharma<sup>1</sup>, Marianne Mathia<sup>1</sup>, M Lzoch<sup>1</sup>, Natascha Simon-Kupilik<sup>1</sup>, Reinhard Moidl<sup>1</sup>, Daniel Zimpfer<sup>1</sup>, Ernst Eigenbauer<sup>2</sup>, Ernst Wolner<sup>1</sup>

<sup>1</sup>Department for Cardiac and Thoracic Surgery

<sup>2</sup>Department of Medical Computer Sciences

University of Vienna, Austria

*Resultados de la sustitución de la válvula aórtica con autoinjerto pulmonar: análisis crítico de la intervención de Ross*

La sustitución de la válvula aórtica utilizando la propia válvula pulmonar del paciente, el autoinjerto pulmonar, conocida como intervención de Ross, ha visto aumentada su popularidad después de una adopción inicial lenta. Hoy día muchos cirujanos la consideran como intervención de elección en niños y pacientes jóvenes. Sin embargo, hay ciertas dudas sobre el comportamiento y resultados alejados tanto del autoinjerto como del homoinjerto utilizado para la reconstrucción del tracto de salida del ventrículo izquierdo.

En esta revisión se efectúa un análisis crítico de los aspectos técnicos de la intervención y de sus modificaciones, se repasan los resultados disponibles de series amplias sobre niños y adultos incluyendo nuestros propios resultados y se discuten los problemas clave del procedimiento, el potencial de dilatación del autoinjerto en la circulación sistémica y la durabilidad del homoinjerto en el tracto de salida del ventrículo derecho.

Concluimos que la intervención de Ross ofrece una reparación duradera y eficaz en niños y adultos jóvenes.

**Palabras clave:** Válvulas. Aorta. Operación de Ross. Autoinjerto. Congénito.

Replacement of the aortic valve with the patients own pulmonary valve, the pulmonary autograft also know as the Ross operation is after initial slow adoption increasingly used. It is today seen by many surgeons as the procedure of choice in children and young adults. However several concerns exist in regard to the long-term fate of the autograft and the homograft used for reconstruction of the right ventricular outflow tract.

In this review we critically assess technical aspects of the operation and modifications, review outcome data available from larger series for both adults and children including our own and discuss the key problems of the procedure, the potential for dilatation of the pulmonary autograft in the systemic circulation and durability of the homograft in the right ventricular outflow tract.

We conclude that the Ross operation offers children and young adults with aortic valve disease a long lasting, effective treatment.

**Key words:** Valves. Aorta. Ross operation. Autograft. Congenital.

«Conferencia invitada en el XII Congreso de la Sociedad Catalana de Cirugía Cardíaca, Barcelona 25 a 28 de Mayo de 2005»

Correspondencia:

Paul Simon, M.D.

Department for Cardiac and Thoracic Surgery

Medical University of Vienna

Waehringuer Guertel 18-20

A-1090 Vienna. Austria

E-mail: paul.simon@univie.ac.at

Recibido 26 mayo 2005

Aceptado 10 julio 2005

In the early, pioneering days of cardiac surgery there was only a limited choice of prostheses available to replace the diseased aortic valve. In addition the hemodynamic and clinical performance were considerably worse compared to modern devices. In 1967 Sir Donald N. Ross described a technique to replace the aortic valve with the patients own healthy, living pulmonary valve, the pulmonary autograft<sup>1</sup>. The right ventricular outflow tract is reconstructed mostly with homografts more infrequently with xenografts. The technical complexity of the procedure, extended aortic cross clamp time and imperfect techniques of myocardial protection prevented most surgeons from adopting the new operation. The increasing appreciation of the complications associated with lifelong anticoagulation needed even with the most current mechanical prostheses<sup>2-4</sup>, the limited durability of biological prostheses in particular in children and young adults<sup>5,6</sup> and the advances of cardiopulmonary bypass and myocardial protection techniques rekindled interest in the Ross operation only more recently.

## SURGICAL TECHNIQUES

The technique initially described by Ross was the subcoronary implantation of the autograft<sup>1</sup>. This technique has the advantage that excision and reimplantation of the coronary ostia is not required. However positioning of the commissures, annular dilatation as well as ectasia of the aortic root are all critically important for leaflet coaptation and valve competence. Hence Ross modified his technique and introduced the root replacement technique in 1974<sup>7</sup> which has become the preferred technique for most surgeons. The full free standing pulmonary root is implanted with reimplantation of the coronary ostia. The geometry of the root and the commissures are preserved minimizing technical errors. However the pulmonary root is exposed immediately to the increased pressure of the systemic circulation and there is concern about early and late dilatation<sup>8</sup>. Subsequently the importance of annular adjustment and fixation to prevent late dilatation, consideration of the relationship of the sino-tubular junction of the ascending aorta which is frequently enlarged in these patients and geometrical considerations in patients with bicuspid aortic valves were recognized to prevent autograft valve incompetence<sup>9</sup>. Techniques to address these problems include the cylinder inclusion technique of implantation, wrapping of the autograft with vicryl net and support of the non-coronary sinus of the autograft with the native aortic wall, annular fixation, ascending aortic replacement<sup>9,10</sup>.

## SHORT TO MID-TERM RESULTS

Numerous reports have demonstrated excellent short and midterm results with low rates of valve related deaths and complications<sup>11-14</sup>. A report from the Spanish national Ross registry shows a mortality of 2,36% and low reoperation rates

with freedom from reoperation at a mean follow-up of 36 months of 92,4%<sup>15</sup>. The recent evaluation of our 15 year experience with the Ross operation (1991-2005) showed a perioperative mortality in 194 patients of 2,6%. The hemodynamic performance at rest and during exercise is physiological and better than in any prosthesis to date<sup>16</sup>.

## LONG-TERM RESULTS

Results beyond 10 years are unfortunately still sparse. In the pioneering series operated by Ross between 1967 and 1984 survival at 10 and 20 years was 85 and 61%, respectively in the 131 hospital survivors<sup>17</sup>. Freedom from reoperation on the autograft was 88 and 75%. Causes of late death were mainly chronic heart failure, death from reoperation and endocarditis. Elkins, et al.<sup>12</sup> reported at the recent AATS meeting 2005 the 16-year results in 464 patients of which 197 were below 18 years of age. Survival at 16 years was 80%. Freedom from autograft degeneration, defined as reoperation or severe insufficiency was 81%. Important differences were noted in this series between patients who were operated for aortic stenosis and insufficiency with a freedom from autograft degeneration of 95 vs. 53% ( $p < 0,002$ ), respectively<sup>18</sup>. There were no thromboembolic or bleeding events and freedom from endocarditis was 94%. Freedom from all valve related events was 63% at 16 years. Kouchoukos, et al.<sup>19</sup> reported follow-up of up to 13 years with a 94% survival at 10 years with 75% freedom from autograft reoperation and 86% from homograft reoperation. Oswald, et al.<sup>20</sup> achieved an excellent 90% survival at ten years although the proportion of patients with endocarditis as the indication for the Ross operation was more than 25%. Freedom from autograft and homograft reoperation were 93 and 98%, respectively. Freedom from reinfection was 98% for both the autograft and the homograft. In our own series of 142 adult patients with follow up extending to 15 years survival was 92% at 13 years and event free survival (death, reoperation and endocarditis were the only events observed) was 85%.

## ROSS OPERATION IN THE PEDIATRIC POPULATION

Even though some have reported good results with mechanical valves in children<sup>21</sup> many series indicate increased complication and reoperation rates<sup>22,23</sup>. Biological xenografts are of low durability in children<sup>24</sup>. The Ross operation was adopted for children<sup>25</sup> and allows to address even multi-stage obstructions of the left ventricular outflow tract at the subvalvular, valvular and supra-valvular level<sup>26,27</sup>. Although the series reported are generally much smaller in number and follow-up is shorter than in adults the Ross operation has emerged as the procedure of choice if valve replacement becomes necessary in a child. Very importantly growth of the pulmonary autograft was

demonstrated not only experimentally, but clinically as well with physiological hemodynamic performance despite considerable increase in body surface area of the patient<sup>28,29</sup>. This may be the most important reason excellent clinical outcomes reported and for low reoperation rates despite considerable somatic growth in this age group<sup>29-32</sup>. We recently updated our own series of 52 children with a mean age of 11,4 years (range: 23 days-17 years) who were operated since 1991. Patient demographics are depicted in Table I. The mean time of follow up is 5 years with a maximum of 14 years. There was 1 perioperative death in a newborn baby who had previous unsuccessful balloon dilatation of critical aortic valve stenosis and left ventricular outflow tract obstruction. Two late deaths occurred of which one was a sudden death in a child scheduled for homograft replacement for rapid degeneration and the other was non-cardiac. Echocardiography showed excellent hemodynamic results at the latest follow up (Table I). Gradients stayed within normal physiological ranges throughout with none of the children having a peak gradient above 20 mmHg. Two patients had reoperations, one for failure of both the autograft and the homograft and the other for prophylactic tissue engineered porcine xenograft replacement<sup>33</sup>. Elkins, et al.<sup>18</sup> reported again at the AATS 2005 an excellent 97% survival in 197 children at 13 years, and freedom from autograft degeneration of 83% at 16 years.

## CONCERNS

### Autograft dilatation

The autograft was shown to retain its cellularity and viability over long implantation periods<sup>17</sup>. It was also shown that adaptive changes occur in the pulmonary root when transposed in the systemic circulation<sup>34,35</sup>. However in patients with bicuspid aortic valves there is an increased fragmentation pattern of the elastic fibers not only in the aortic root but was also observed in the pulmonary root<sup>36</sup>. These structural changes have been implicated in the development of progressive dilatation of the autograft root and may lead to reoperation<sup>8</sup>. Even aneurysm formation and dissection have been observed<sup>37,38</sup>. However these can be treated with a valve sparing operation i.e replacement of the diseased root and ascending aorta with a vascular prosthesis and resuspension of the pulmonary autograft valve within the prosthesis if the leaflets appear unaffected and normal. We have previously reported that in fact dilatation of the autograft occurs<sup>39</sup>. There is clear evidence of a time dependent dilatation of the autograft root. At one, two, five and seven years freedom from dilatation was 80, 62, 48 and 45%, respectively. The sinus increased by a mean of 7.6% from the early to the last follow-up. However the amount of dilatation was less than 25 in 90% of patients. Even though we observed dilatation of the autograft root clinically relevant aortic insufficiency did not develop. We identified as important risk factor for dilatation observed in our study was the

**TABLE I. PEDIATRIC PATIENTS WITH ROSS OPERATION**

Gender	Male	37	Female	15
Surgery	Ross	43	Previous interventions/surgery	33
	Ross-Konno	5	RVOT reconstruction	HG 47
	Ross+other	4		XG 5
Echocardiography			discharge (n = 52)	last FU (n = 49)
	AI	0-1	49	39
		1-2	3	9
		2.5	0	1
	Gradient	> 20	0	0
	PI	0-1	42	33
		1-2	5	12
		> 2	6	3
	Gradient	> 20	5	25
		> 50	0	6

RVOT: right ventricular outflow tract; HG: homograft; XG: xenograft.

time from surgery, with an annual rate of dilatation of 1.4% percentage points and the initial diameter of the autograft. Since we did not find that dilatation up to 25% of the initial diameter was associated with progressive aortic insufficiency considerable tolerance of the pulmonary root may be assumed. Male gender was also found to be a risk factor for dilation with an increase in diameter of 9.2 in men vs. 0.9% in women when they have the same underlying initial sinus. Technical considerations seem also to be of importance<sup>9</sup>.

### Right ventricular outflow tract

The Ross operation requires reconstruction of the right ventricular outflow tract and critics maintain that aortic valve disease is turned into “double valve disease”. The substitute most commonly used is the pulmonary homograft. Homograft degeneration and reoperations are acceptable even in the long-term<sup>18-20</sup>. Freedom from homograft replacement in the pulmonary position was 80% at 20 years in the pioneer series<sup>17</sup>. Although in contrast to the autograft growth of the homograft does not occur durability is still satisfactory in children<sup>28</sup>. In our series only one homograft out of 51 implanted in children over a 15 year period had to be replaced. However many children have developed moderate pulmonary insufficiency and gradients over 20 mmHg and six even a gradient over 50 mmHg (Table I). An important risk factor for degeneration is young age and therefore all attempts towards valve preserving procedures should be made in the very young<sup>40</sup>. Previous use of a homograft has also been identified as a risk factor for accelerated homograft degeneration<sup>41</sup>. Other types of xenograft<sup>42-44</sup> and tissue engineered conduits<sup>33</sup> have been used with mixed results but do not seem to be able currently to match results of homografts.

## SUMMARY

The Ross operation can be considered today the procedure of choice in children and adolescents and young women of child bearing age. The available long-term information suggest that aortic valve replacement with the pulmonary autograft may also

be superior in young adults. However at 15 to 20 years valve related events mainly reoperations are not negligible and a personalized patient oriented and informed decision has to be made in individual cases.

## REFERENCES

- Ross DN. Replacement of aortic and mitral valves with a pulmonary autograft. *Lancet* 1967;2:956-9.
- Cannegieter SC, Rosendaal FR, Briet E. Thromboembolic and bleeding complications in patients with mechanical heart valve prosthesis. *Circulation* 1994;89:635-41.
- Kratz JM, Crawford FA, Sade RM, Crumbley AJ, Stroud MR. St. Jude prosthesis for aortic and mitral valve replacement: A ten-year experience. *Ann Thorac Surg* 1993;56:462-8.
- Moidl R, Simon P, Wolner E, and the members of the ON-X prosthesis heart valve trial. *Ann Thorac Surg* 2002;47:S1312-7.
- Al-Khaja N, Belboul A, Rashid M, et al. The influence of age on the durability of Carpentier-Edwards biological valves. *Eur J Cardio-thorac Surg* 1991;5:635-40.
- Jamieson WR, Rosado LJ, Munro AI, et al. Carpentier-Edwards standard porcine bioprosthesis: primary tissue failure (structural valve degeneration) by age groups. *Ann Thorac Surg* 1988;46:155-62.
- Ross DN. Replacement of the aortic valve with a pulmonary autograft: the "switch" operation. *Ann Thorac Surg* 1991;52:1346-50.
- David TE, Omran A, Ivanov J, et al. Dilatation of the pulmonary autograft after the Ross procedure. *J Thorac Cardiovasc Surg* 2000;119:210-20.
- Moritz A, Domanig E, Marx M, et al. Pulmonary autograft valve replacement in the dilated or asymmetric aortic root. *Eur J Cardio-Thorac Surg* 1993;7:405-8.
- Klena JW, Shewiki E, Mahaffey HW. Annuloplasty and aortoplasty as modifications of the Ross procedure for the correction of geometric mismatch. *J Heart Valve Dis* 2000;9:195-9.
- Kouchoukos NT, Davila-Roman VG, Spray TL, Murphy SF, Perrillo JB. Replacement of the aortic root with a pulmonary autograft in children and young adults with aortic valve disease. *N Engl J Med* 1994;330:1-6.
- Elkins RC. The Ross operation: a 12-year experience. *Ann Thorac Surg* 1999;68 (Suppl. 3):S14-8.
- Moidl R, Simon P, Aschauer C, et al. Does the Ross operation fulfill the Objective Performance Criteria established for new prosthetic heart valves? *J Heart Valve Disease* 2000; 9:190-4.
- Takkenberg JJ, Dossche KM, Hazekamp MG, et al. Dutch Ross Study Group. Report of the Dutch experience with the Ross procedure in 348 patients. *Eur J Cardio-thorac Surg* 2002;22:70-7.
- Concha M, Pradas G, Juffe A, Caffarena JM, Montero A, Aranda PJ. Comprehensive experience with the Ross operation in Spain. *Eur J Cardio-Thorac Surg* 2003;24:521-6.
- Da Costa F, Haggi H, Pinton R, Lenke W, Adam E, Costa IS. Rest and exercise hemodynamics after the Ross procedure: an echocardiographic study. *J Cardiac Surg* 1998;13:177-85.
- Chambers JC, Somerville J, Stone S, Ross DN. Pulmonary autograft procedure for aortic valve disease; long-term results of the pioneer series. *Circulation* 1997; 96:2206-14.
- Elkins RC, Elkins CC, Lane MM, et al. Ross operation-sixteen year experience. *AATS* 2005;70: abstr. 4.
- Kouchoukos NT, Masetti P, Nickerson NJ, Castner CF, Shannon WD, Davila-Roman VG. The Ross procedure: long-term clinical and echocardiographic follow-up. *Ann Thorac Surg* 2004;78:773-81.
- Oswalt JD, Dewan SJ, Mueller MC, Nelson S. Highlights of a ten year experience with the Ross procedure. *Ann Thorac Surg* 2001;71(5 Suppl):S332-5.
- Alexiou C, McDonald A, Langley SM, Dalrymple-Hay MJ, Haw MP, Monro JL. Aortic valve replacement in children: are mechanical prostheses a good option? *Eur J Cardio-thorac Surg* 2000;17:125-33.
- Lupinetti FM, Warner J, Jones TK, Herndon SP. Comparison of human tissues and mechanical prostheses for aortic valve replacement in children. *Circulation* 1997;96:321-5.
- Robbins RC, Bowman FO Jr, Malm JR. Cardiac valve replacement in children: a twenty year series. *Ann Thorac Surg* 1988;45:56-61.
- Williams DB, Danielson GK, McGoon DC. Porcine heterograft valve replacement in children. *J Thorac Cardiovasc Surg* 1982;85:446-50.
- Gerosa G, McKay R, Ross DN. Replacement of the aortic valve or root with a pulmonary autograft in children. *Ann Thorac Surg* 1991;51:424-9.
- Reddy VM, Rajasinghe HA, Teitel DF, Haas GS, Hanley FL. Aortoventriculoplasty with pulmonary autograft: the "Ross-Konno" procedure. *J Thorac Cardiovasc Surg* 1996;111:158-65.
- Erez E, Kanter KR, Tam VK, Williams WH. Konno aortoventriculoplasty in children and adolescents: from prosthetic valves to the Ross operation. *Ann Thorac Surg* 2002;74:122-6.
- Simon P, Ascauer C, Moidl R, et al. Growth of the pulmonary autograft after the Ross operation in childhood. *Eur J Cardio-thorac Surg* 2001;19:118-21.
- Al-Halees Z, Pieters F, Quadoura F, Shahid M, Al-Amri M, Al-Fadley F. The Ross procedure is the procedure of choice for congenital aortic valve disease. *J Thorac Cardiovasc Surg* 2002;123:437-41.
- Elkins RC, Lane NM, McCue C. Ross operation in children late results. *J Heart Valve Dis* 2001;10:736-41.
- Ohye RG, Gomez CA, Ohye BJ, Goldberg CS, Bove E. The Ross/Konno procedure in neonates and infants: intermediate-term survival and autograft function. *Ann Thorac Surg* 2001;72:823-30.
- Hraska V, Krajci M, Haun C, et al. Ross and Ross-Konno procedure in children and adolescents: mid-term results. *Eur J Cardio-thorac Surg* 2004;25:742-7.
- Simon P, Kasimir MT, Seebacher G, et al. Early failure of the tissue engineered porcine heart valve Synergraft™ in pediatric patients. *Eur J Cardio-thorac Surg* 2003;23:1002-6.
- Carr-White GS, Afoke A, Birks EJ, et al. Aortic root characteristics of human pulmonary autograft. *Circulation* 2000;102:III-15.
- Rabkin-Aikawa E, Aikawa M, Farber M, et al. Clinical pulmonary autograft valves: Pathologic evidence of adaptive remodeling in the aortic site. *J Thorac Cardiovasc Surg* 2004;128:552-61.
- de Sa MP, Moshkovitz Y, Butany J, David TE. Histologic abnormalities of the ascending aorta and pulmonary trunk in patients with bicuspid aortic valve disease: clinical relevance to the Ross procedure. *J Thorac Cardiovasc Surg* 1999;118: 588-94.
- Ishizaka T, Devaney EJ, Ramsburgh SR. Valve sparing aortic root replacement for dilation of the pulmonary autograft and aortic regurgitation after the Ross procedure. *Ann Thorac Surg* 2003;75:1518-22.
- Luciani GB, Favaro A, Viscardi F, Bertolini P, Mazzucco A. Valve-sparing root replacement for pulmonary autograft dissection late after the Ross operation. *J Thorac Cardiovasc Surg* 2004;128:753-6.
- Simon-Kupilik N, Bialy J, Moidl R, et al. Dilatation of the autograft root after the Ross operation. *Eur J Cardiothorac Surg* 2002;21:470-3.
- Niwaya K, Knott-Craig CJ, Lane MM, Chandrasekaran K, Overholt ED, Elkins RC. Cryopreserved homograft valves in the pulmonary position: risk analysis for intermediate-term failure. *J Thorac Cardiovasc Surg* 1999;117:141-7.
- Stark J, Bull C, Stajevic M, Jothi M, Elliot M, de Leval M. Fate of subpulmonary homograft conduits: determinants of late homograft failure. *J Thorac Cardiovasc Surg* 1998;115:506-14.
- Dittrich S, Alexi-Meskishvili VV, Yankah AC, Dahmert I, et al. Comparison of porcine xenografts and homografts for pulmonary valve replacement in children. *Ann Thorac Surg* 2000;71:717-22.
- Pearl JM, Cooper DS, Bove KE, Manning PB. Early failure of the Shelhigh pulmonary valve conduit in infants. *Ann Thorac Surg* 2002;74:542-8.
- Breyman T, Thies WR, Boethig D, Goerg R, Blanz U, Koerfer R. Bovine valved venous xenografts for RVOT reconstruction: results after 71 implantations. *Eur J Cardio-thorac Surg* 2002;21:703-10.