Modification of the Ross aortic valve replacement to prevent late autograft dilatation

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Abstract

Objective: Aortic root dilatation with and without aortic regurgitation is seen in up to 20% of patients undergoing a Ross aortic root replacement at late follow-up. We present our early experience with reduction annuloplasty combined with prosthetic Dacron graft replacement of the aorta above the autograft to prevent late dilatation after a Ross aortic root replacement. Methods: Since 2001, 31 of 97 adult and paediatric patients (mean age 28.8 ± 14.4 years; range 8–53 years) with bicuspid aortic valve and dilatation of the ascending aorta underwent a modified Ross procedure with reduction annuloplasty combined with prosthetic Dacron graft replacement of the ascending aorta. The diameter of the ascending aorta was measured before and early after surgery and then between 3 months and 8 years follow-up (mean, 2.5 ± 2.2 years). Results: There were no early or late deaths. Reduction annuloplasty combined with ascending aortic graft replacement decreased the diameters of the ascending aorta from 42 ± 7.0 mm preoperatively to 25 ± 2.9 mm early after surgery (p < 0.001). During follow-up, there was no significant increase of the aortic diameter compared with that during the postoperative period (27 ± 4.3 mm; p = 0.07). The root diameter increased in only 3 of 31 patients (10%). No patient underwent re-operation. At last follow-up, mild (n = 18) or trivial (n = 13) aortic regurgitation was observed. Conclusion: Ross aortic root replacement combined with reduction annuloplasty and Dacron graft replacement of the ascending aorta demonstrated excellent early- to mid-term results in patients with bicuspid aortic valve and dilatation of the ascending aorta. Continued use and long-term follow-up imaging is necessary to further demonstrate the value of this technical modification.

Keywords: Aortic valve replacement; Pulmonary autograft; Ross procedure; Dilatation

1. Introduction

Replacement of the diseased aortic valve by pulmonary autograft, a procedure initially described by Ross [1], has been shown to provide excellent haemodynamic results, both in children and in young adults, and to be associated with low morbidity and mortality rates [2–4]. It became a worldwide-accepted procedure for aortic valve replacement (AVR) despite the need for specific surgical expertise to perform this complicated operation on both the aortic and pulmonary valves.

The pulmonary autograft has excellent haemodynamic adaptation; there is no need for anticoagulation; patients can lead an active lifestyle; and patient survival seems to be superior when compared with survival of patients with other valve substitutes [5,6]. However, in recent years, the number of reports on re-operation rate after the Ross operation using root replacement is becoming increasingly common, thus questioning the durability of the autograft [7–9].

Aortic root dilatation with and without aortic regurgitation (AR) is seen in up to 20% of patients undergoing the Ross aortic root replacement at late follow-up. Patients with bicuspid aortic valves and dilated ascending aortas or patients with dilated aortic roots and primarily AR have been considered the highest-risk group for dilatation and neo-aortic insufficiency in some series [7–10]. We had similar concerns due to annular sinus, and ascending aortic dilatation requiring re-operation was seen early in our series of Ross operations [3,11]. Since these early failures, we have modified our approach to the aortic root.

We present our early experience with reduction annuloplasty combined with prosthetic Dacron graft replacement of the aorta above the autograft to prevent late dilatation after the Ross aortic root replacement.

2. Materials and methods

This study was approved by the Institutional Review Board (IRB) of the Indiana University School of Medicine as a
Thirty patients had a preoperative diagnosis of congenital aortic valvular disease with mixed aortic stenosis (AS) and AR, and one patient had predominantly AR. Preoperative AR was moderate in 21 (68%) patients, severe in four (13%) and mild in six (19%) patients. One patient had acquired AR from acute bacterial streptococcal endocarditis that had damaged the aortic valve. Nine patients (29%) had undergone prior surgical aortic valvuloplasty and two had a prior aortic balloon valvuloplasty. Twenty-seven patients had bicuspid aortic valves and four had unicuspid valve. Additional procedures performed at the time of the Ross operation included sub-aortic membrane resection (n = 2) and Konno enlargement (n = 1). Twenty-five patients had aneurysmal dilated ascending aorta (>35 mm), and in the other six patients the size of ascending aorta was >30 mm. The mean size was 42 ± 7.0 mm (range: 30–60 mm).

### 2.1. Operative procedures

We performed the Ross operation in all cases as an autograft root replacement, as described previously [3,11]. All patients had intra-operative trans-oesophageal echocardiography (TEE). Standard techniques of cardiopulmonary bypass were used, with bicaval cannulation, moderate hypothermia and antegrade and retrograde cold blood cardioplegia. The right ventricular outflow tract (RVOT) was then reconstructed with an appropriately oversized (6–10 mm larger than the autograft) cryopreserved pulmonary homograft (SynerGraft; n = 10) (CryoLife, Inc., Marietta, GA, USA) and bovine jugular vein conduit (Contegra, Medtronic Inc., Minneapolis, MN, USA; n = 1).

The distal aortic anastomosis was completed with a 5-mm Dacron strip incorporated into the anastomosis to prevent postoperative annular dilatation (Fig. 1). In all patients we replaced the aorta with a Hemashield graft measuring 2 mm or smaller than the autograft annulus. Annular reduction was indicated when the aortic valve annulus was more than 4 mm larger than the pulmonary valve annulus. The annulus was reduced from 42 ± 7.0 mm (range: 30–60 mm) to 25 ± 2.9 mm (range: 20–32 mm; p < 0.001). Annular reduction was performed using a 5-mm-wide Dacron strip (Boston Scientific Corp., Natick, MA, USA) placed circumferentially around the aortic annulus and taking smaller bites of the Dacron and wider bites of the aortic annulus, thus pleating the aortic annulus 2–3 mm per mattress suture along the left and non-coronary portions of the aortic annulus. The annular reduction was measured by placing an appropriately sized Hegar dilator through the aortic annulus.

The proximal autograft suture line was fixed with a Dacron strip, as described above, routinely after 2000 when the aortic annulus was 20–24 mm and annular growth was not desired. All patients required ascending aortic root replacement with a synthetic tube graft. The mean graft size was 25 ± 2.6 mm (range: 20–30 mm). ATEE was carried out intraoperatively in all the patients after the cardiopulmonary bypass weaning to evaluate the competence of the aortic valve. None of the patients showed AI greater than mild.

Table 1 shows the operative, postoperative and follow-up data. A preoperative z value at the site of sinuses of Valsalva was +1.5 ± 0.2 (range: +1.0 to +2.5).

### 2.2. Statistical analysis

Measured and calculated data are expressed as mean ± standard deviation (SD). Comparison of continuous and binary variables between two time points (preoperative or postoperative or at follow-up) were performed using Student’s t-test or Wilcoxon signed-rank test. Early mortality was defined as death during initial hospitalisation or within 30 days of operation. Any deaths later than that were defined as late mortality. A p-value of less than 0.05 was considered significant. Specific statistical software SPSS for Windows version 10 (SPSS Inc., Chicago, IL, USA) was used for data analysis. A z value of autograft sinuses of Valsalva was calculated according to the regression equations published by Roman and colleagues from the BSA and the echocardiographically derived measurement [12].

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**Fig. 1.** A modified Ross procedure with reduction annuloplasty in combination prosthetic Dacron graft replacement of the ascending aorta.
increased in only 3 of 31 patients (10%).

1004 average follow-up of 2.5–3.3. Follow-up or stenosis with normal biventricular kinetics in all patients. (range: 3–13 days). Pre-discharge echocardiographic exam-

patients had postoperative complications: re-explorations due to bleeding (1). All patients recovered regular sinus rhythm. Three patients were easily weaned from bypass and had good valvular function as determined by intra-operative TEE.

3. Results

3.1. Operative results

All patients underwent modified Ross aortic root replacement with the pulmonary autograft with reduction annuloplasty combined with prosthetic Dacron graft replacement of the ascending aorta with the above-described technique, and all survived the operation. Mean aortic cross-clamp time was 94 ± 24 min (range: 75–158 min) and mean cardiopulmonary bypass time was 133 ± 28 min (range: 101–168 min). All patients were easily weaned from bypass and had good valvular function as determined by intra-operative TEE.

3.2. Postoperative course

The postoperative recovery in the intensive care unit was an average of 2 days (range: 1–8 days). Eleven patients (36%) were extubated in the operation room, 19 (61%) on the first postoperative day on intensive care unit and one on day 2 after surgery. All patients recovered regular sinus rhythm. Three patients had postoperative complications: re-explorations due to bleeding (n = 1) and due to right coronary artery problem (n = 1), and remaining patient had compartment syndrome of the left leg. Length of hospital stay was a mean 5.8 ± 2.3 days (range: 3–13 days). Pre-discharge echocardiographic examination demonstrated absence of semilunar valve regurgitation or stenosis with normal biventricular kinetics in all patients.

3.3. Follow-up

There were no deaths or reinterventions during an average follow-up of 2.5 ± 2.2 years (range: 3 months to 8 years). No infective or embolic events were reported by the patients or referring physicians following up.

The echocardiographic data demonstrated lasting resolution of the left ventricular outflow tract obstruction (LVOTO) with peak pressure gradients ranging from 10 to 22 mmHg (mean, 15.2 ± 3.8 mmHg). AR was trivial in 13 patients and mild in 18. Comparing the diameter of the aortic annulus at the early postoperative and follow-up examination, there was no aortic root enlargement in proportion to somatic growth suggesting growth and/or dilatation of the autograft (25 ± 2.9 mm vs 27 ± 4.3 mm; p = 0.07). The root diameter increased in only 3 of 31 patients (10%).

Fifteen patients had trivial pulmonary regurgitation, 15 had mild regurgitation and one had moderate regurgitation. No patients had significant pulmonary homograft obstruction during follow-up, with an estimated mean gradient of 19 ± 8.9 mmHg (range: 10–38 mmHg). Left and right ventricular functions were normal in all patients. At last follow-up, z value at the site of sinuses of Valsalva is 0.5 ± 0.2 (range: 0.2–1.0; p < 0.001).

4. Discussion

This review of 31 patients with bicuspid aortic valve and dilatation of the ascending aorta who underwent a modified Ross AVR with reduction annuloplasty combined with prosthetic Dacron graft replacement of the ascending aorta at our institution over 8 years (since 2001) adds to the growing body of literature demonstrating that the Ross AVR is a relatively safe and effective treatment for aortic valvular disease.

The valve annulus, sinuses of Valsalva and sinotubular junction (STJ) of the pulmonary autograft are known to show an increase in size after the Ross AVR [9,10,13]. This increase may be secondary to passive dilatation due to exposure to higher blood pressure [14], mismatch of the pulmonary autograft and the aortic annulus or ascending aorta [15], an intrinsic abnormality of the pulmonary root possibly associated with congenital bicuspid aortic valve disease [13] or normal somatic growth in the paediatric population [16]. When the root dilatation leads to significant autograft valve regurgitation, or when the dilatation rapidly progresses into an aneurysm, re-operation is indicated. The treatment options are a mechanical valve Bentall procedure [17], replacement of the aortic root with a homograft [13], replacement of the aortic valve with supported or unsupported aortoplasty [18], separate replacement of the aortic valve and the ascending aorta [19] or valve-sparing root replacement [20].

Regarding the role of autograft length in the root techniques, de Kercove and colleagues found that systematic dilatation in patients with long autograft and maximal diameter more frequently observed at the level of the STJ [21]. They conclude that in the root technique, autograft is better when it is as short as possible, with the distal suture line reinforced with a Teflon strip or extended with a Dacron...
We reduce the aortic annulus if it is dilated. Elkins and colleagues [24]. By contrast, this sinus and the STJ dilate with time as the annulus grows proportionally to the somatic growth of the patient. We have observed that the aortic root dimensions immediately after the Ross AVR, and needed reduction. We presently use aortic annulus and STJ with a Dacron strip unless the aortic annulus was dilated in our institution (two hospitals) in a non-randomised manner. Data were acquired retrospectively from one institution (two hospitals) in a non-randomised manner. The authors identified dilatation of the STJ as an independent predictor for progression of AR.

Because aortic root dimensions and regurgitation develop with time, Horer and colleagues performed parametric analysis of repeat longitudinal echo data to describe changes of dimensions and regurgitation [24]. The authors determined that the aortic root dimensions immediately after the Ross AVR were larger than in normal healthy children, but the annulus grows proportionally to the somatic growth of the child [24]. By contrast, this sinus and the STJ dilate with time following Ross AVR. AR develops slowly but significantly and is associated with a dilated STJ.

Our experience raises several technical and patient selection concerns. Autograft root and ascending aortic dilation ± autograft regurgitation was the most common cause of autograft re-operation early in our Ross experience. The most common cause of autograft regurgitation was dilatation of the autograft sinuses and STJ, particularly in patients where AR was the primary lesion. Early in our experience, we did not routinely fix the aortic annulus and/or STJ with a Dacron strip unless the aortic annulus was dilated and needed reduction. We presently use aortic annulus and STJ fixation with synthetic material in all older adolescents and adults whose aortic annulus (z score) is greater than +1. We reduce the aortic annulus if it is dilated. Elkins and colleagues describe that the only independent predictors of development of moderately severe or severe autograft regurgitation were increasing age at the time of the operation, autograft regurgitation at completion of the operation and increasing follow-up time [2].

Patients with dilated ascending aorta (>40 mm) are at increased risk for late development of progressive ascending aorta dilatation and autograft regurgitation. Since 2001, we have replaced the dilated ascending aorta with a Dacron graft to support the STJ of the autograft. We do not feel that reverting to a subcoronary or inclusion cylinder would be uniformly helpful in this subset. Annulus reduction and fixation should be considered in all older patients with predominant AR and any other patient who has an aortic annular diameter 4 mm greater than pulmonary annulus diameter. In the past several years, we have adopted Elkins’s recommendation to replace the ascending aorta if it is significantly dilated >35 mm². We also routinely treat systemic hypertension aggressively postoperatively with beta-blockers and angiotensin-converting enzyme (ACE) inhibitors to prevent autograft dilatation and subsequent regurgitation. The aortic annulus and STJ must be at least 20 mm in diameter before we restrict their growth with a Dacron band. We did not see any infants or very young patients with moderate dilatation at the level of the aortic annulus or STJ. The youngest patient who needed aortic annulus reduction was an 8-year-old, and we reduced his annulus to 20 mm.

5. Conclusions

We believe the Ross AVR is, and should continue to be, an important procedure for the treatment of aortic valve disease. However, neo-sinus of Valsalva dilatation and neo-aortic regurgitation remain serious shortcomings of the procedure. This study demonstrated that reduction anuloplasty in combination prosthetic Dacron graft replacement of the ascending aorta in patients with preoperative ascending aortic dilatation is a good option.

6. Limitations

A number of important limitations are present in this analysis. Data were acquired retrospectively from one institution (two hospitals) in a non-randomised manner. The operations were performed by four surgeons and the decision of operative methods was determined by the preoperative diagnosis and the surgeons’ preferences. The population size is small with a relative short follow-up, which could increase the risk for a Type II error.

References

you replace the ascending aorta now in many instances with a Dacron graft, With these modifications you make it a little bit more complex, which means quite a complex operation, not the easiest operation in our armamentarium.


Appendix A. Conference discussion

Dr P. Kappetein (Rotterdam, The Netherlands): The Ross technique is quite a complex operation, not the easiest operation in our armamentarium. With these modifications you make it a little bit more complex, which means you replace the ascending aorta now in many instances with a Dacron graft, and my question is related to that. You do this operation specifically for a group of patients where you think they need the valve to last for a very long time. What is currently your indication? For which patient group do you perform this operation? Do you have an age limit? Do you have an indication limitation there?

**Dr Brown:** The upper age limit continues to change. It sort of goes along with my age limit. I am in my 60s, and if I needed an aortic valve replacement, I would want a Ross technique by somebody who does a lot of them, if I had a good pulmonary valve. So there is no age limit. There are a number of groups that think we ought to eliminate this dilated aortic root with a bicuspid valve because they think the ascending aortic pathology is such that these patients will become late problems. And it just turns out, we just replace the aortic root and the ascending aorta at the time of the original Ross, and I am not sure the sinuses of the pulmonary root are any different. We use relatively large coronary buttons so that two of the three sinuses get replaced with aortic tissue, and it seems that in this high-risk group why deny the patient the benefits of the Ross if the late follow-up seems good.

The other thing, there is another operation that we can do. In those few patients early in our series that developed aortic root dilatation, particularly the sinuses in the ascending aorta, a valve-sparing root replacement is an excellent operation and we can still salvage the Ross valve.

**Dr Kappetein:** What we know from the Ross series that we have seen so far is that after year 12 to 14 after the Ross operation, it starts failing; you see more insufficiency of the aortic valve. What do you expect from this series? Will something like this happen as well? Is there a chance it will recur? Are you really convinced even after 12 to 14 years it will still look very good?

**Dr Brown:** The follow-up in our entire series extends back 16 years, and when we looked, only 20% of the patients who had the Ross in the first half of this series developed any root dilatation. So we are talking about a small segment of patients, 20%, that developed these late problems, and I am hoping that the modifications that we have outlined here today will prevent the vast majority of those patients from having the problem, and we hope that the re-operation rate is going to be exceedingly low long term, but time will tell. We need more follow-up.

**Dr M. Hazekamp (Leiden, The Netherlands):** We already spoke about this issue earlier this year, I think, but to go on with the second comment of Dr Kappetein, I indeed think it is a question of time. So if you wait longer, let’s say 10 to 12 years, especially in those patients who have a bicuspid aortic valve and an already dilated ascending aorta, there may be a fair risk of getting autograft dilatation even if you support the ascending aorta above the autograft and the annulus under it. Because my colleague, Paul Schoor, who worked with me in Leiden for several years, did a lot of studies on autograft explants, and what you see (and it seems to be more so in patients who have a bicuspid aortic valve) is that there is a problem with the wall tissue of the pulmonary autograft, that the fibres tend to disarray, look abnormal, and that may be one of the causes of later dilatation. So I am not sure that after 10 to 12 years you will be completely rid of this problem.

**Dr Brown:** Mark, I think that is an excellent comment. The trouble is you are only looking at the ones you explanted. You are not looking at the ones that you did not explant. And I have a feeling if the sinuses get very stretched, there is the disarray of collagen in that group of patients, and I think all of us if we look back at the explanted tissues will find that that tissue is abnormal. But in my mind, that is still not a reason to deny. If you can prevent it, you ought to prevent it. Number two, if you even do get it, you have got a good fallback operation and give the patient a viable valve that potentially could last the patient the rest of his life.

**Dr Hazekamp:** Okay, that is true, I agree with you, but maybe it would be better to wrap it or put it in a subcoronary position, as that will prevent it, absolutely.

**Dr Brown:** Well, I think you are right. It turns out that a difficult operation for many cardiac surgeons is a coronary implantation, and the root technique has allowed the Ross to be offered and performed by a good number of cardiac surgeons and feel comfortable with it. But again, time will tell. We will need another decade to know for sure whether this is going to hold up for the long term.

**Dr V. Falk (Zurich, Switzerland):** I have just one question regarding the long-term perspective. The overall numbers of the Ross procedure actually decline rather than increase. New oral anticoagulant drugs with fewer side effects may make the use of mechanical valves more attractive in the future. At the same time, biological valves now last for 20 years and longer and new options for transcatheter valve-in-valve implantation for prosthetic valve failure are on the horizon. In this context where do you see the role of the Ross operation?
Dr Brown: All of these techniques will take their place. For the child and for the young adult, I don’t think there is anything that compares with the Ross aortic valve replacement, and, to my knowledge, as supported by Yacoub and others, this is the only type of aortic valve replacement that puts you back on the normal survival curve. No other aortic prosthesis puts you back on the normal life expectancy curve.

Dr Kappetein: I slightly disagree with that last statement, because we don’t have long-term follow-up of these patients; they are relatively young. And if you see that the patient has to come back several times after his first Ross operation failed, and then he gets a mechanical valve plus perhaps an ascending aorta replacement, I can hardly imagine that they will have the same life expectancy as a normal population.

Dr Brown: Well, obviously it will take a lot more patients other than the ones reported to date to find out if this is going to hold true, but at least there are a couple of reports in the literature now that would indicate that it compares quite favourably to other types of aortic valve replacements.