The Ross Procedure reassessed

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Rationale

The search for an ideal biological heart valve substitute has been going on for half a century. In 1960 Lower and Shumway described the feasibility of replacing the aortic valve in dogs with a native pulmonary valve. In London, Ross had already pioneered the homograft clinically in 1962 but it had become clear that a valve taken from a deceased person would have a limited durability. To use the pulmonary valve which has the same embryological origin as the aortic valve and is a living autologous valve substitute, was a ground breaking idea. In 1967 Ross performed this procedure (on humans) and replaced the pulmonary valve with an aortic homograft in a patient predicting that placed in a low pressure, high compliance circuit, the durability of the homograft would be greater than in the systemic circulation. It was reasoned that the pulmonary autograft, although subjected to systemic pressure would, as a living valve, be able to adapt. As it turns out, the aortic valve has several sophisticated features that are dependent on its viability. The different parts of the aortic valve change their size and shape during the cardiac cycle. This property can affect left ventricular workload and possibly coronary flow, together with stress distribution on the valve leaflets. Furthermore, living aortic valve leaflets modify their stiffness in response to humoral and endothelial-derived signals, allowing them to adapt to changes in haemodynamic conditions.

Early Results of the Ross Procedure

In the year 2000, David and colleagues reported that the pulmonary autograft dilated and that the dilation was often accompanied by aortic regurgitation due to outward displacement of the three commissures. David compared the results of the free standing autograft root to the aortic root inclusion technique. Several other authors confirmed the findings of early dilatation in the free-standing neo-aortic root. As this problem became widely known, fewer surgeons continued to perform the operation, but Sievers re-examined the problem and adapted the original sub-coronary technique with some minor changes and demonstrated excellent valve function and lack of dilation of an aortic root at medium term follow up of 7-8 years.

In 2009 Takkenberg undertook a meticulous, systematic review and meta-analysis of all publications on the Ross procedure in the preceding 8 years. 39 studies were selected which contained information on early mortality and long term outcomes such as late deaths and re-operations. The authors controlled heterogeneity caused by age by dividing the population into three categories: consecutive series in children and adults, adult patients, and a paediatric series. Early mortality and linearised rates of post operative adverse events were calculated for each study and pooled on a logarithmic scale using the inverse variant method in a fixed effects model. Some of the series included were quite small containing only 31 patients. As David has pointed out series such as these will include most of the learning curve and are therefore likely to skew the results. The mean follow up study ranged from 1 to 8.7 years and was less than 5 years in 59% of the studies. The pooled early mortality was 3.0% in consecutive series of children and adults, 3.2% in adults and 4.2% in children but there was a wide variation among reports from <1.0% to 6.8%. Takkenberg reported the late mortalities at 0.5%, 0.6% and 0.6% respectively according to the three groups but there was also considerable variation among different reports.

In this review structural failure and non-structural failure leading to re-operation were analysed together and ranged widely among the various reports analysed. They found that the failure of the autograft was high in children and in young adults. The pooled linearised rates were 1.2%/year in consecutive series of children and adults, 0.8%/year in adult patients and 1.4%/year in paediatric series.

Results

The largest three series in the literature have been reviewed in Table 1. The early mortality is low at 1-2%. In a young population in whom the pulmonary autograft is ideally suited it should be around 1%. Late survival figures are remarkably consistent between the two series of David and El-Hamamsy of around 95% for 13-15 year follow up (Table 2).

Table 1: Actuarial survival, early (30 days) and late (13-15 years) after the Ross procedure.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Early survival % [SD]</th>
<th>Late survival % [SD]</th>
</tr>
</thead>
<tbody>
<tr>
<td>David TE</td>
<td>2009</td>
<td>99% [0.4%]</td>
<td>96.6% [1.5%]</td>
</tr>
<tr>
<td>El-Hamamsy I</td>
<td>2010</td>
<td>98% [1.0%]</td>
<td>95.0% [3.0%]</td>
</tr>
<tr>
<td>Elkins RC</td>
<td>2008</td>
<td>97% [2.0%]</td>
<td>92.0% [2.0%]</td>
</tr>
</tbody>
</table>

Table 2: Freedom from (FF) autograft failure at 10 and at 15 years after the Ross procedure.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>FF autograft failure at 10yrs % [SD]</th>
<th>FF autograft failure at 15yrs % [SD]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elkins RC</td>
<td>2008</td>
<td>86% [2.0%]</td>
<td>74% [5.0%]</td>
</tr>
<tr>
<td>David TE</td>
<td>2009</td>
<td>Not given</td>
<td>93% [2.2%]</td>
</tr>
<tr>
<td>El-Hamamsy I</td>
<td>2010</td>
<td>99% [1.1%]</td>
<td>99% [2.6%]</td>
</tr>
</tbody>
</table>

Ideally the pulmonary autograft should be long lasting but the freedom from autograft failure or re-operation range from 99-86% at 10 years in the largest series and 99-74% at 13-16 years. The commonest cause of autograft failure remains dilation of the aortic root. But this can be greatly minimised by meticulous attention to detail and by placing the proximal suture line of the autograft root within the left ventricular outflow tract, thus ensuring adequate support. It is also important to place the sutures in the autograft 1-2 mm from the hinge of the valve leaflet. The use of strict hypertensive treatment for the first 6-12 months post operatively with a beta-blocker to achieve a blood pressure of 100 to 110mmHg systolic is thought to be important so as to reduce stress on the neo-aortic valve.
The fate of the pulmonary homograft in the right ventricular outflow tract has also been carefully studied. In larger series freedom from re-operation on the RVOT varies from 90-82% at 10 years but by 13 years in some series, as Takkenberg points out, the figure for freedom from re-operation falls to 51%. Currently the failing pulmonary homograft needs to be replaced by a porcine or bovine tissue valve and can often be achieved using a percutaneous technique. Measures to improve RVOT homograft durability include the use of pulmonary homografts, the administration of anti-inflammatory drugs to suppress the specific immune response of the recipient to the homograft. Developments in tissue engineering may enable the use of more durable biological valved conduits for the reconstruction of the RVOT.

**Histological Aspects**

Rabkin-Aikawa and colleagues reported that explanted autografts are viable and have an almost normal tri-laminar leaflet structure with regard to collagen architecture but the walls of the autograft are varied with focal abnormalities involving smooth muscle cells, elastin and collagen. Another recent histological study by Schoof and colleagues found that compared with normal pulmonary and aortic valves, explanted autograft valves also have an intact lamina structure with the aorta and the pulmonary root each having their own typical function and design. Consequently the pulmonary root has a different stress-strain curve relationship than a normal aortic root with a greater extensibility at lower strain levels. It is therefore reasonable to expect the neo-aortic root to stretch beyond its normal transitional point of high to low extensibility. This is supported by an in-vitro analysis of pulmonary root dynamics. Considering the thin wall and dilated neo-aortic root, it is plausible that the autograft is subjected to significantly elevated stresses and the observed histological changes of elastin (distensibility) and collagen increase (integrity) are modes of adaptation in which functional priority is shifted to the maintenance of integrity. Despite this adaptation excessive wall stress may induce intimal tearing creating a localised chronic dissection. Nevertheless, there are no reports so far of acute dissection arising from a dilated neo-aortic root after a Ross procedure.

Changes in root geometry and dynamics influence valve function and durability. The autograft valve leaflets can remodel towards an aortic phenotype but the autograft root is unlikely ever to do so. Further studies are needed to elucidate the underlying mechanisms.

**The Ross controversy**

Although the Ross pulmonary autograft operation is used by surgeons whose work includes children growing up with congenital disease of the aortic valve, it is rarely used for adults having aortic stenosis and normal sized aortic root. It is also very appropriate for children with aortic stenosis who often have had a valvotomy early in life because it remains the only valve substitute that will allow growth in the child.

To avoid long-term complications, post-operative hypertension needs to be treated aggressively for the first 6 months, an external support is required at the new sino-tubular junction, and if the ascending aorta is dilated it should be replaced at the initial Ross operation.

**Conclusion**

The ideal candidate for a Ross procedure is a young adult with aortic stenosis and normal sized aortic root. It is also very appropriate for children with aortic stenosis who often have had a valvotomy early in life because it remains the only valve substitute that will allow growth in the child.

Essentially, we have to offer the patient a choice of risks: a haemorrhagic stroke after a mechanical prosthesis or a reoperation for biological valve degeneration. As Treasure suggests, a better research strategy might be modelling and individualised patient information by simulation.

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**Table 3: Freedom from (FF) reoperation on the right ventricular outflow tract (RVOT) after the Ross Procedure.**

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>FF reop RVOT at 10 yrs % [SD]</th>
<th>FF reop at 15 yrs % [SD]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klieverik LM</td>
<td>2007</td>
<td>87.1% [5.5%]</td>
<td></td>
</tr>
<tr>
<td>Elkins RC</td>
<td>2008</td>
<td>90% [2.0%]</td>
<td>82% [4.0%]</td>
</tr>
<tr>
<td>David TE</td>
<td>2009</td>
<td>88%</td>
<td></td>
</tr>
<tr>
<td>El-Hamamsy I</td>
<td>2010</td>
<td>82% [5.0%]</td>
<td>51% [8.0%]</td>
</tr>
</tbody>
</table>

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**References**


