The Ross operation: Aortic valve and root replacement with pulmonary autograft
The search for the ideal substitute for the diseased aortic valve led Donald Ross to develop the concept of the aortic allograft and pulmonary autograft for subcoronary implantation in the 1960s and in the early 1970s as a full root to replace aortic roots with abscesses [1–5]. Allograft aortic valve replacement was pioneered by two surgeons, Mr. Donald Ross himself in London and Sir Brian Barratt-Boyes in Auckland, New Zealand, independently of each other in 1962 [1, 6].

During the last century, the aortic allograft and pulmonary autograft surgical procedures revolutionized the history of cardiac valve surgery. They compete well with bioprostheses, being non-thrombogenic and, thus, requiring no postoperative anticoagulation. They are also resistant to infection and restore the anatomy of the aortic or pulmonary outflow tract, which ensures unimpeded blood flow and excellent hemodynamics, thus, offering patients a better prognosis of survival with good quality of life. Initial results were unsatisfactory due to technical problems of implantation and early tissue failure of the allograft valves due to lack of proper decontamination and preservation techniques.

Over time, the pulmonary autograft (Ross operation) has proven to be the preferred device for valve replacement in young patients in whom growth of the valve replacement is anticipated. It is a challenging double-valve procedure consisting of subcoronary aortic valve or aortic root replacement which requires surgical skill and experience to achieve good results. The operation technique has gained popularity and acceptance among today’s pediatric surgeons.

Both the pulmonary autograft and aortic allograft have gained popularity in the management of acute endocarditis with root abscesses because of their resistance to infection. Aortic allograft is absolutely indicated for aortic root abscess with aortic ventricular dehiscence and drug addicts [10]. Their superiority over prosthetic valves has been demonstrated in many reports [7–13].
Results

The pulmonary autograft in the aortic position

The operative mortality rate for patients with endocarditis is reported to be 5–12% and the rate of reinfection is estimated to be 0–3% at 5 years [11, 12]. In patients with noninfected aortic root, hospital mortality is 0.6–3.9%. In the series of Elkins et al., in which most of the patients underwent root replacement, survival at 16 years was 82%, actuarial freedom from autograft reoperation and tissue failure was 80% and 74%, respectively, and for freedom from autograft endocarditis it was 95%. In children, actuarial freedom from autograft failure at 16 years was 83% and survival was 84%. The 16-year freedom from allograft reoperation was 82% [14]. Actuarial freedom from reoperation for the subcoronary implantation technique at 8 years in the series studied by Schmidtke et al. was 95% [11, 15].

The overall operative mortality reported from the German-Dutch Ross Registry in this volume was 1.4%; however, the rate of postoperative endocarditis for a pulmonary autograft in the aortic position and an aortic allograft in the pulmonary circulation was 14% and 21%, respectively [11].

Long-term results over 20 years are available only from the series of patients operated on by Ross himself. Of 225 survivors operated on by Ross, reoperation was performed in 17 (7.5%) patients due to technical failures and in 7 (3%) due to tissue failure during the 20 years of follow-up. There were 7 (3%) valve-related deaths and 8 (3.5%) other nonvalve-related deaths. The actuarial freedom from valve failure or reoperation on the aortic allograft in the pulmonary circulation was 81% and freedom from valve-related death was 97% (Table 2) [16].

Table 1. Surgical results of active infective native and prosthetic valve endocarditis according to type of valve replacement. A review of the literature

<table>
<thead>
<tr>
<th>Source</th>
<th>Years</th>
<th>30-day mortality (%)</th>
<th>Reinfected/PL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Allo/PA</td>
<td>Prosthesis</td>
</tr>
<tr>
<td>Knosalla et al. [22]</td>
<td>11</td>
<td>8.5</td>
<td>23.5</td>
</tr>
<tr>
<td>Petrou et al. [17]</td>
<td>11</td>
<td>8.3</td>
<td>na</td>
</tr>
<tr>
<td>Haydock et al. [8]</td>
<td>15</td>
<td>17</td>
<td>20.7</td>
</tr>
<tr>
<td>Yankah et al. [10]</td>
<td>17</td>
<td>9.3</td>
<td>na</td>
</tr>
<tr>
<td>d’Udeckem et al. [23]</td>
<td>8</td>
<td>na</td>
<td>13</td>
</tr>
<tr>
<td>Niwaya et al. [12]</td>
<td>13</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Niwaya et al. [12]</td>
<td>13</td>
<td>12</td>
<td>na</td>
</tr>
</tbody>
</table>

PA pulmonary autograft, PL paravalvular leak, na not available
Aortic allograft in the aortic position

The operative mortality of allograft patients with active infective endocarditis was estimated to be 4–14% [10, 17]. Survival at 10 years and 15 years was 87% and 70%, respectively. The incidence of early reinfection was 1–4% and was associated with perivalvular leak and pseudoaneurysm formation [10, 17]. Freedom from recurrent infection and reoperation for all causes at 10 years and 15 years was 97% and 80%, respectively [17]. The reoperative hospital death rate after replacement of reinfected allograft ranged from 4 to 9.3% [9, 10, 17].

The 15- and 20-year survival of allograft patients with sterile aortic roots in our series was 65% and 58%, respectively. Late death was 5.6%. The estimated freedom from reoperation for all causes was 76% and 50% at 15 and 20 years, respectively. Actuarial freedom from structural deterioration at 15 years was 47% in patients under 20 years of age and 81% in patients between 41 and 60 years [18]. Freedom from explantation of undersized and matched allografts at 15 years was 48% and 77%, respectively [19].

Aortic root replacement

Patient survival was 71% for patients with a root replacement at 15 and 20 years. Freedom from structural valve deterioration (SVD) of 82.9% and 56% at 17 and 25 years, respectively, was documented [7, 10].

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Table 2. Long-term results of pulmonary autograft (the Ross operation) and allograft replacement of the aortic valve and root. A review of the literature*

<table>
<thead>
<tr>
<th>Follow-up (years)</th>
<th>PA</th>
<th>Aortic allograft</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>487</td>
<td>618</td>
</tr>
<tr>
<td>Mean age at op. (years)</td>
<td>24</td>
<td>51</td>
</tr>
<tr>
<td>Hospital mortality (%)</td>
<td>3.9</td>
<td>5</td>
</tr>
<tr>
<td>Free of SVD (%)</td>
<td>74</td>
<td>62/18</td>
</tr>
<tr>
<td>Free of reoperation</td>
<td>80</td>
<td>81/35</td>
</tr>
<tr>
<td>Free of graft infection</td>
<td>95</td>
<td>93/89</td>
</tr>
<tr>
<td>Patient survival</td>
<td>82</td>
<td>67/35</td>
</tr>
</tbody>
</table>

* Elkins et al. [14], Lund et al. [7], O’Brien et al. [18], Yankah et al. [10].

PA pulmonary autograft
**Freehand subcoronary aortic valve replacement**

The survival rate of patients with subcoronary implantation was 45%, 33%, and 23% at 15, 20, and 25 years. Freedom from SVD was 63.5% and 15% at 17 and 25 years, respectively. Patients with undersized allograft and tailored aortic root who underwent freehand AVR had 48% and 13% freedom from reoperation at 10 and 15 years, respectively [7, 10].

**Comments**

Understanding of the use of pulmonary autografts and aortic and pulmonary allografts, from the bench to clinical practice, is probably universal for surgeons, especially those of the younger generation, homograft bankers, and scientists.

The surgeon has the medical and ethical responsibility to use a pulmonary autograft and aortic and pulmonary allograft valves to treat patient with aortic and pulmonary valvular disease. What we have accepted as critically important to pulmonary autograft and allograft recipients is the implanting surgeon’s skill and scientific and clinical knowledge as well as quality control, which determine the outcome of the patient.

Lerich put it simply and effectively: “The great problem of surgery is a problem of knowledge.” Allan Callow in Boston complemented this by saying that better science, which means better data, is making better medicine possible. Proof of the durability of viable allografts came from the longer follow-up series of Lund and O’Brien [18].

To provide perspective and to emphasize the state of the art, a brief review of current clinical practice is warranted. It is now recognized that the clinical results and durability of aortic and pulmonary allografts depend not only on tissue viability, recipient and donor age, and immune response, but also on valve sizing and the implantation technique.

A full root replacement is associated with a low incidence of valve dysfunction and of early reoperation. Aortic root tailoring or reduction annuloplasty of a large aortic annulus during freehand subcoronary aortic valve replacement appears to carry a high risk of valve failure and early reoperation. Patients with undersized allograft and tailored aortic root who underwent freehand AVR had freedom from reoperation of 48% and 13% at 10 and 15 years, respectively [7, 10]. In the learning phase of autograft, allograft root and freehand subcoronary aortic valve implantation, the rate of reoperation for technical, nonstructural valve failure will obviously be relatively high [7, 18]. The technical errors are associated with a geometric mismatch between the anatomic units of the aortic root, resulting in paravalvular leak, central leak, cusp rupture, leaflet prolapse or distortion, commissural displacement or progressive aortic root dilatation (annuloectasia, Marfan’s syndrome).
Aortic annulus reinforcement with teflon or glutaraldehyde-fixed equine pericardial strips after aortic root replacement was suggested by Ross and others to prevent progressive annular dilatation of the pulmonary autograft and in patients with annuloectasia undergoing allograft root replacement [20, 21]. While others prefer the aortic root replacement technique for the Ross operation, Sievers has demonstrated that the freehand subcoronary implantation technique requires no aortic annulus reinforcement because the implantation technique itself provides protection against postoperative root dilatation and ensuing valve incompetence [11, 15]. It is, therefore, a fact that the implantation techniques of the pulmonary autograft constitute the technical artistry of the Ross operation.

The operative mortality rate of allograft patients with active infective endocarditis was estimated to be 4–14% compared to 5–12% for the Ross operation [10, 17]. Reoperative hospital death rate after replacement of reinfected allografts in our series was 9.3% and is comparable to that of other reports [17]. Recurrent endocarditis was the most common cause of death in allograft patients. The incidence of early reinfection was 1–4% as compared to 0–3% in autograft patients [10, 11, 12, 17]. Actuarial freedom from reinfection in allograft patients at 10 and 15 years was 81–97% and 72%, respectively [10, 17]. Survival at 10 and 15 years in endocarditis patients with allografts was found to be 82% and 70.4%, respectively [10, 17]. Survival of allograft patients at 15 and 20 years was 64.8% and 58%, respectively, in our series. In other series, survival of allograft patients at 15, 20, and 25 years was 48%, 35%, and 26% [7]. There was a significant difference in survival among patients with different allograft implantation techniques. Others reported long-term survival of 71% for patients with root replacement at 15 years; for patients with subcoronary implantation, it was 45%, 33%, and 23% at 15, 20, and 25 years, respectively [7, 10, 18]. Survival of autograft patients with root technique at 16 years was 82%, while in children it was 84% [21].

In O’Brien’s follow-up of patients with allograft aortic valves, the estimated freedom from reoperation for all causes was 76% and 50% at 15 and 20 years, respectively. Structural deterioration at 15 years was 47% in patients under 20 years of age and 81% in patients between 41 and 60 years [18]. In other series, the actuarial freedom from allograft explantation at 15 years was 48% for undersized and 77% for matched valves [19]. Patients aged 53 years who were undergoing allograft aortic root replacement have shown freedom from reoperation for structural valve deterioration (SVD) of 82.9% and 56% at 17 and 20 years, respectively, as compared to 82% for autograft in patients aged 24 years at 16 years [7, 10, 21].

In conclusion, the pulmonary autograft in the aortic position (the Ross operation) should be considered the valve of choice for surgical treatment of active infective endocarditis in children and adolescents, although long-term data are not yet available. Allograft replacement of the aortic valve can be performed with good results but the risk of early degeneration limits its use in children, except in rescue operations.
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References

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