

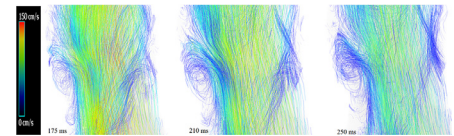
Surgical Heritage: You Had to Be There, Ross: The Comeback Kid

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Half a century after the first pulmonary autograft operation (Ross operation), performed in 1967 by Donald Ross in central London, there is a very strong conviction that the Ross operation is the best available valve substitute today, not only for children, but also for younger and older adults. The Ross operation has stimulated a lot of science to do with tissue-engineering and biology of heart valves, which is a promising avenue for the future. For one of us (M.Y.), it has certainly been a privilege to be associated with the comeback of the Ross operation.

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The Ross operation ensures laminar, unobstructed flow with retained vortices in the aortic sinuses.

Central Message

The Ross operation's journey over the past decades has been characterized by many refutations by peers, igniting worldwide collaborative research ranging from better understanding its biology, advancing tissue engineering to perfecting its application in the clinic. One thing is sure: Ross, the comeback kid, is here to stay.

INTRODUCTION

Science does not progress in a predictable, slow manner, but usually by imaginative leaps,¹ followed by a painstaking process of refutations, usually supplied by peers.¹ This is precisely what has happened with the Ross operation. One of us (M.Y.) was privileged to witness the whole process from the beginning. This review constitutes an in-depth analysis of this almost unique experience.

NATIONAL HEART HOSPITAL, LONDON 1967

The National Heart Hospital (Fig. 1) is where it all started one morning in 1967, when the first Ross operation was performed. The operation was based on several conjectures by Donald Ross (Fig. 1) which were not clearly discussed with the

team prior to doing the first operation. At that time, Donald Ross correctly postulated that a living heart valve is essential for more durable performance as well as providing better quality of life. It took approximately 50 years to evaluate these hypotheses²⁻⁵ and now it is generally agreed that the Ross operation is indeed the best valve substitute for not only children and young adults, but also for older adult patients requiring a reasonable longevity and quality of life.^{6,7} It remains the only valve substitute that is associated with a restored life expectancy. This has been recently confirmed by a real-world evaluation of long-term outcomes of different aortic valve substitutes by El-Hamamsy,³ clearly showing that the Ross operation is the only option associated with optimal survival that resembles survival in the matched general population, unlike survival after use of mechanical or biological prostheses (Fig. 2).

MAJOR TEETHING PROBLEMS

As with so many surgical innovations, the initial teething problems of the Ross operation were multiple and complex. During autograft harvesting, one of the major challenges was to avoid injuring the first septal perforator, which can produce persistent bleeding difficult to control, as well as possibly a septal infarction, causing hemodynamic instability. This problem was solved by improved understanding of myocardial vasculature and subsequent alterations in autograft harvesting.

Another problem was the lack of external support provided by the muscular pulmonary root (Fig. 3). This was remedied by a simple technical modification ensuring insertion of the

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Abbreviations

- cm** centimeters
- LC** left coronary sinus
- mm** millimeters
- NC** noncoronary sinus
- RC** Right coronary sinus
- UK** United Kingdom

pulmonary autograft inside the fibrous annulus of the aortic root.

As the pulmonary autograft is translocated from a low-pressure environment to the high-pressure of the systemic circulation,⁸ it is essential to allow it time to adapt^{9,10} by preventing perioperative systemic hypertension using vasodilators and beta blockers. This period of adaptation, with systolic pressures below 120 mm Hg, should be extended for at least 3-6 months.¹¹

ROOT REPLACEMENT VERSUS SUBCORONARY POSITION

There has been an ongoing debate on the superiority of each of these techniques. The original Ross operation was placed in the subcoronary position.⁸ It became apparent that early autograft incompetence, a serious issue in the early experience, was mainly due to progressive dilatation of the aortic root in some patients (Fig. 4), but autograft dilatation is not invariable.¹² The exact cause of the variability is the subject of extensive studies.¹³ Moreover, reports of severely degenerated autografts came from those implanted in the subcoronary position (Fig. 5).¹⁴ This is thought to be due to persistent oscillation of the component parts of the root following the subcoronary technique. In contrast, the full root guarantees optimal positioning of these components. Previous studies on aortic homografts suggested the superiority of outcome following the full root technique when compared to the subcoronary technique.¹⁵ The full root technique is more reproducible and allows better preservation of the dynamism of the aortic valve.

In patients at risk for dilatation, this hazard can be mitigated by recently introduced technical adjuncts to the Ross operation.¹⁶ Currently, our group uses a technique of autologous



Figure 1 The National Heart Hospital in London, UK (left), and surgeon Donald Nixon Ross (right).

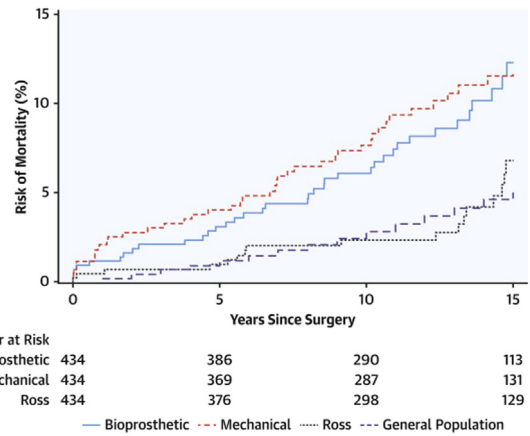


Figure 2 Long-term cumulative incidence of all-cause mortality after the Ross operation (gray), mechanical aortic valve replacement (red), and biological aortic valve replacement (blue), compared with the matched general population in the United States (purple). Adapted from El-Hamamsy et al.³ (via: <https://doi.org/10.1016/j.jacc.2021.11.057>).

“loose jacket” support¹⁶ (Fig. 6), in an attempt to prevent late dilatation while maintaining laminar flow and vortices in the sinuses of Valsalva (Figs. 7 and 8). Moreover, no significant loss of energy is seen and both ventriculo-arterial coupling as well as wall shear stress are normal years after surgery (Fig. 8). This technique preserves geometry of the neo-aortic root and avoids the use of prosthetic material. Introduction of foreign materials such as Dacron or Teflon below or above the autograft during the original Ross operation have been shown to induce infection and fibrosis. The Ross operation is preferably performed without use of foreign materials to embrace the concept of a living valve substitute.

In patients with isolated severe aortic regurgitation who have a discrepancy between the size of the native aortic annulus and the pulmonary root, intertrigonal compression plication is performed.

THE FUTURE

The Ross operation has also stimulated a very large number of basic science studies to do with the biology and tissue engineering of the aortic root. It has fueled the beginning of a

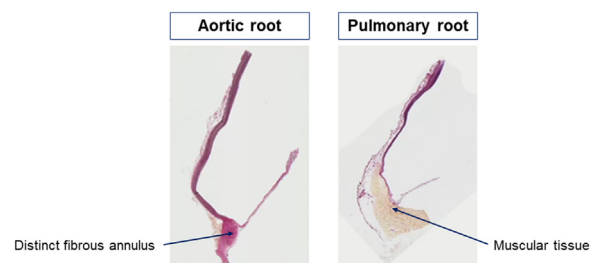


Figure 3 Coupe of the noncoronary aortic sinus including aortic valve leaflet (left) and of the nonfacing pulmonary sinus including pulmonary valve leaflet (right).

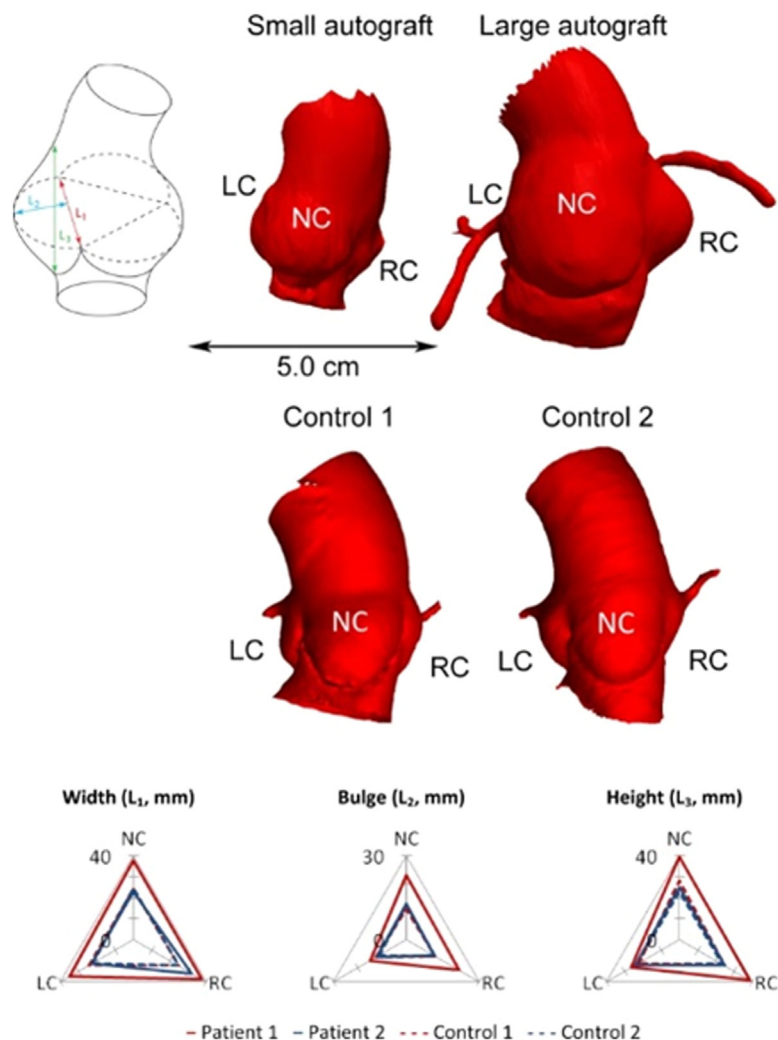


Figure 4 Variability in aortic root dilatation after the Ross operation, showcasing a small autograft and an enlarged autograft after a full root replacement. Adapted with author permission from Torii et al.¹² Abbreviations: cm, centimeters; LC, left coronary sinus; mm, millimeters; NC, noncoronary sinus; RC, right coronary sinus.

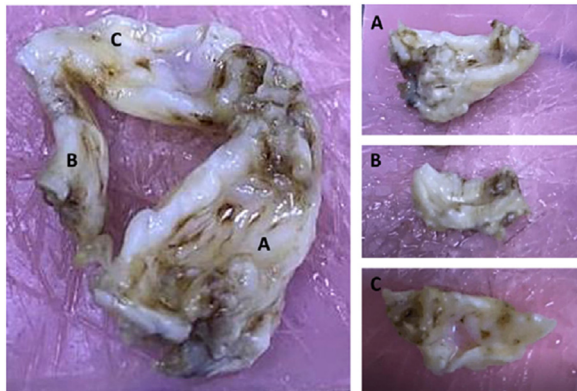


Figure 5 Severely degenerated autograft after a subcoronary technique. Adapted with author permission from Latif et al.¹⁴

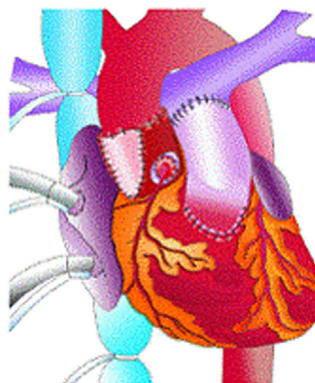


Figure 6 Loose jacket technique for autograft implantation. The native aortic root can be seen wrapped around the left and right autograft sinuses and a triangular autologous pericardium strip to provide external autologous support to the non-facing autograft sinus. Adapted with author permission from Afifi et al.¹⁶ (CC BY-NC-ND 4.0 license: <https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode>).

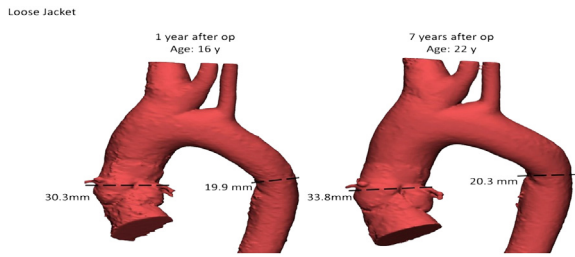


Figure 7 Computed tomography reconstruction of autograft dimensions over a period of up to 7 years after the Ross operation utilizing the loose jacket technique. Only growth proportional to somatic growth was observed. Adapted with author permission from Afifi et al.¹⁶ (CC BY-NC-ND 4.0 license: <https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode>).

society which meets every 2 years, looking at these 2 topics. Collaborative efforts by individuals that embraced the hypotheses of the Ross operation have advanced this new field of research. The concept of in situ regeneration has produced very encouraging results in recent years.¹⁷

CONCLUSIONS

The Ross operation is finding its way back into practice.⁵ Not only the operation can be reproducibly applied in experienced centers, but also this is being reported increasingly.¹⁸ Due to the technical complexity of the procedure compared to conventional aortic valve replacement, these should be performed in Ross centers of excellence.¹⁸ It has been a privilege to be associated with the comeback of the Ross operation.

DECLARATION OF COMPETING INTEREST

None.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Magdi H. Yacoub: Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Maximiliaan L. Notenboom:** Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Giovanni Melina:** Investigation, Writing – original draft, Writing – review & editing. **Johanna J.M. Takkenberg:** Investigation, Resources,

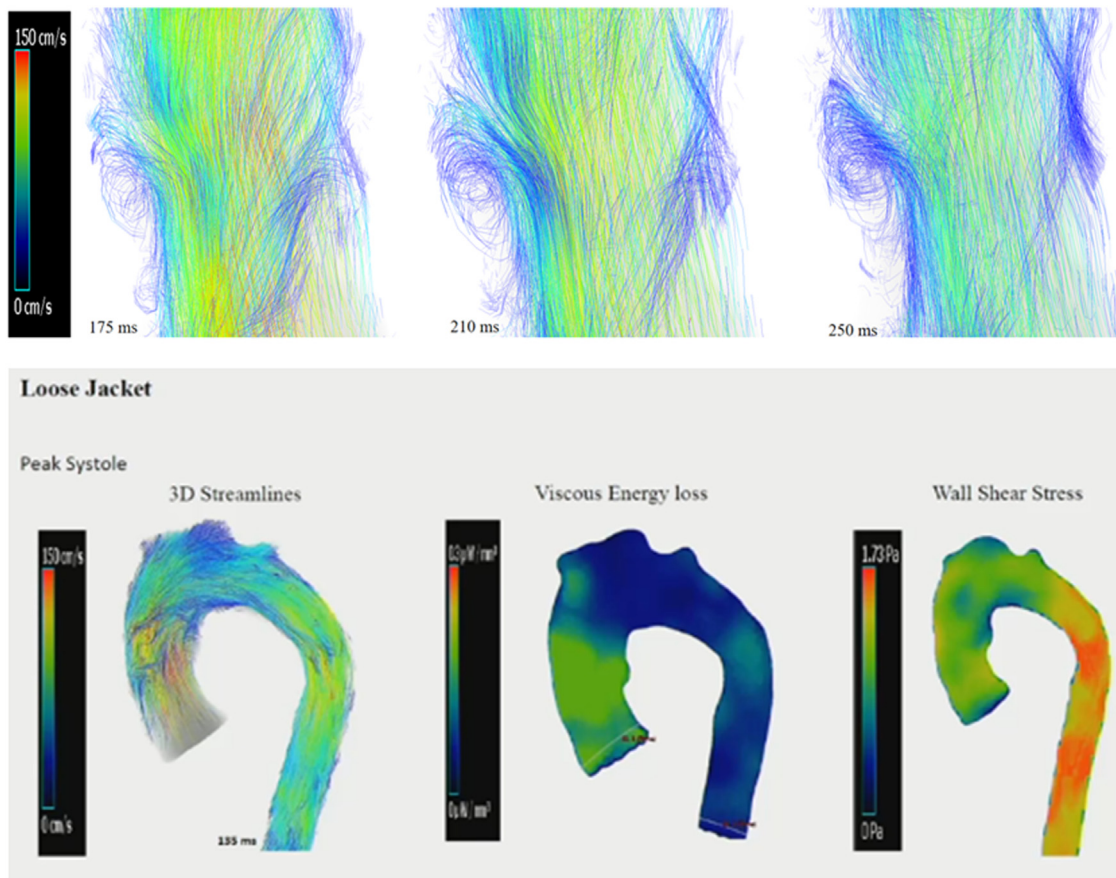


Figure 8 4D flow magnetic resonance imaging reconstruction of an autograft after loose jacket technique. Laminar, unobstructed, flow with retained vortices in the aortic sinuses (upper), normal wall shear stress, and without significant loss of energy in an autograft root with preserved geometry (lower). Adapted with author permission from Afifi et al.¹⁶ (CC BY-NC-ND 4.0 license: <https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode>).

Writing – original draft, Writing – review & editing, Supervision.

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