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Review Article

The Ross Operation in the Adult: What, Why, and When?

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The normal aortic valve is a sophisticated and dynamic structure whose equal replacement has not yet been actualized by modern technology. The use of the pulmonary autograft as a substitute for a diseased aortic valve (the Ross procedure) has been in practice for several decades in many types of patient. In the adult, it has not been adopted widely due to concerns about its technical challenge, complex perioperative care, the development of pulmonic valve disease, and concerns about long-term dilatation of the neo-aortic root, among others. There has been a substantial body of data showing excellent long-term survival, freedom from reoperation, and quality of life, in contradistinction to these preconceptions. The authors review the available data pertinent to these questions to further define the role of the Ross procedure in the adult cardiac surgery patient.

Key Words: aortic root; The Ross Procedure; aortic valve; pulmonary valve; coronary arteries

THE NORMAL AORTIC root is a highly sophisticated structure, consisting of many cell types, arranged into the aortic valve leaflets, the fibrous annulus, the sinuses of Valsalva and the sinotubular junction.[1,2] The structure is essential to its function, allowing the rapid passage of a bolus of blood with minimal turbulence and minimal regurgitation. Donald Ross, an English cardiac surgeon, developed the harvesting of the pulmonary autograft for implantation in the aortic position in the 1960s[3] (Fig 1).[4] The rationale was simple. The right-sided ventriculoarterial valve is also trileaflet, and its constituent parts are the same as the aortic valve, apart from the lack of a true fibrous annulus. Its great advantage over homografts, xenografts, and mechanical prosthesis is that it is a "living valve," capable of replicating the sophisticated functions of the native valve.[5] This technique, using the pulmonary autograft in the aortic position, gathered momentum but was superseded by perceived advances in mechanical and tissue valves, namely ease of implantation. Its use today is limited to children and a few specialized centers that continue to perform the surgery in adults.

Early replacements of the aortic valve were crude but have evolved in an effort to mimic the performance of the native valve.[6–8] Despite these advances, the use of mechanical and biologic prostheses continue to be associated with an underappreciated latent mortality and morbidity, which has been documented in multiple studies, and includes reoperation.[9–12] Indeed, young patients stand the most to lose as the chance of survival is a competing interest with the risk for reoperation. Those under the age of 60 receiving biologic valves have a risk for reoperation of $\leq 50\%$ in the first decade.[13] Although

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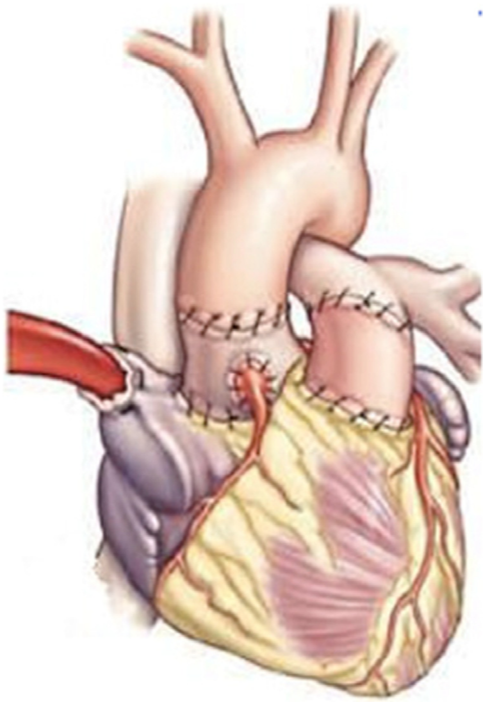

Fig 1. The Ross Procedure. The Ross involves removal of the pulmonary valve and root down to right ventricular outflow tract muscle and replacement of the aortic root using this harvested autograft. The coronaries are reimplanted. The pulmonary valve is replaced with a pulmonary homograft.

the performance of prosthetic valves has improved dramatically, none is capable of the dynamism and structural sophistication of a living aortic valve.[14] Homograft root replacement for aortic valve replacement (AVR) has been used successfully since the 1960s but has fallen somewhat out of favor due to concerns about limited durability and progressive calcifications, making for challenging reoperations.[15,16]

Commonly used valve substitutes consist of a simple bileaflet mechanical design or decellularized animal pericardium constructed into a trileaflet design, which often is stented to ease implantation. Porcine stentless valves offer the possibility of low gradients and the other advantages of biologic valves but with some elevated technical difficulty in implantation. With the advent of stented valves, which are implanted substantially easier and more predictably, stentless valves have become less popular and have a substantially unfulfilled promise. Mechanical valves require lifelong anticoagulation. Prosthetic valve designs fall far short of the aforementioned sophisticated structure and function of the native valve. Indeed, careful analysis of the available data on the long-term performance of aortic valve prostheses is not reassuring. Mihaljevic et al document excess mortality in young patients receiving tissue aortic bioprostheses over time,[11] and multiple other studies document the same phenomenon in biologic or mechanical valves.[9,10] There is good evidence that freedom from biologic and mechanical valve-related complications is underestimated. Kulik et al showed that in patients ages 50 to 65 years, freedom from valve-related complications is 70% for mechanical valves and 41% for biologic valves at 10 years.[12] These complications include thromboembolism, endocarditis, major bleeding, or need for reoperation. Bleeding and thromboembolism issues are worse for mechanical valves where warfarin is used aggressively. Mechanical valves are subject to a low rate of failure, from pannus ingrowth over time.

Although the normal physiology is mimicked most closely by the Ross procedure,[7,17] there remains a perception that the Ross is so technically difficult and invasive, converting a single-valve pathology to a dual-valve pathology, and is laden with latent morbidity from neo-aortic root dilatation and pulmonic homograft failure. The data continue to be in direct contradistinction to these perceptions.[18–22] Indeed, the Ross is the only aortic valve operation with a survival curve indistinguishable from the age- and sex-matched population in some series[23] and excellent very-long-term outcomes, even accounting for reoperation.[24] This has led to the question of whether a renaissance is needed in the use of the Ross, and if it is grossly underused.[22,25] Here, the authors reviewed the operation; its technical points; intraoperative management; and the data currently available concerning long-term survival, performance, and quality of life.

The Native Aortic Root

The advantages of a Ross procedure are best explained through an understanding of the native aortic root, the composite structure of which allows the passage of a stroke volume of blood many times a minute with minimal loss of energy and turbulence. This occurs 3 billion times in an average human lifetime with remarkable resistance to failure. Often thought to be a simple trileaflet outlet valve, the aortic valve-root complex is a highly sophisticated structure conserved in evolutionary biology across a wide range of species.[26] This conservation implies that it provides some advantage, only increasing the challenge in creating equally elegant surgical aortic valves.

Grossly, it consists of the 3 aortic valve leaflets, the annulus, the sinuses of Valsalva, and the sinotubular junction. These structures are living and dynamic; the root continually changing shape throughout the cardiac cycle to maximize unobstructed flow (Fig 2).[1] In systole, the root adopts a more cylindrical shape to allow bulk egress of blood with minimal transaortic gradient and minimal loss of energy. These conformational changes are antecedent to the contraction of the ventricle, implying that the root is a critical physiologic component of the ventriculoarterial system and is subject to feed-forward regulation. The leaflets contain matrix, fibroblasts,[27] different populations of smooth muscle cells, myofibroblasts, endothelial cells, and neuronal components.[28] These cell components are different on either side of the leaflets. Myofibroblasts are capable of contraction and are responsive to stimulation. It has been hypothesized that this sophisticated function underlies the resistance of the valve to structural deterioration. Several studies show that explanted Ross valves have preserved cellularity, that is that they are living and capable of the biologically sophisticated functions of the native valve.[20,29] The pulmonary autograft affords a living autograft

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