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Editorial

Pulmonary autograft replacement of the aortic valve

The choice of a valve prosthesis is particularly important in children, women of childbearing age, and adults with an active lifestyle or separate medical problem. No single device is suitable for all patients. The continuing debate centres on mechanical valves, which require anticoagulation, and bioprostheses, which are not as durable.[1 2] Unfortunately, investment in research and development must be included in the price of newer, more sophisticated valves.

The perfect valve would last indefinitely, provide central non-obstructive flow without haemolysis, and carry no risk of thromboembolism (without requiring anticoagulation). Evidence over 25 years indicates that the autogenous pulmonary valve will function indefinitely with freedom from calcification, thromboembolism, and risk of bleeding as long as normal leaflet coaption is established at operation.[3 4] The pulmonary autograft remains alive and will grow with the child or teenager.[5] The biological problems of homograft degeneration are transferred to the low pressure pulmonary position where optimal valve function is less important and failure occurs slowly.[6] The pulmonary autograft is ideal for aortic replacement in infancy, childhood, and the teenage years. Protagonists now advise the operation for any patient with a life expectancy of more than 20 years.

Evolution of the pulmonary autograft operation

Leonardo da Vinci (1452–1519) characterised the haemodynamics of the aortic valve using a glass model of the aortic sinuses. With his prototype of the pulse duplicator and particles of carbon in the hydraulic fluid, da Vinci identified the mechanism of closure of the native aortic valve and would never have considered stent mounting. Donald Ross together with da Vinci and the Almighty, considered the human aortic and pulmonary valves to have the perfect design to ensure central non-obstructive flow without haemolysis or thromboembolism.[7]

The first homograft operations were performed by Murray,[8] and then by Beall and colleagues who inserted the valve into the descending aorta (like the original Hufnagle ballvalve).[9] Ross's landmark subcoronary homograft implant (24 July 1962) followed the pioneering work of Gunning and Duran in Oxford, who established the method for valve harvest and preparation in dogs.[10] Biggelow had previously implanted a homograft in the orthotopic position in 1961 but the patient died from coronary thrombosis soon after operation. Ross's successful case was followed (24 August 1962) by that of Barratt-Boyes at Green Lane Hospital.[11] Soon afterwards Paneth assisted by O'Brien at the Brompton Hospital implanted a homograft that had been preserved in formalin for 6 months.[12]

Mechanical prostheses then offered the prospect of durability in a range of sizes whereas crude homograft preservation techniques caused early clinical failure.[13 14] The homograft operation was more demanding at a time when myocardial preservation was primitive and there was less appreciation of the homograft's haemodynamic superiority. In the late 1960s to simplify implantation aortic homografts were mounted on a frame and used for aortic, mitral, and tricuspid replacement.[15] These valves were easy to implant and stent mounting significantly decreased the incidence of early postoperative aortic regurgitation, experienced through imperfect commissural alignment of free aortic grafts. However, medium term follow up showed that the durability of the stent mounted homograft tissue was limited. A shortage of human cadaveric material led to studies of the patient's own tissue. In Zurich, Senning removed fascia lata from the thigh and fashioned this into a trileaflet valve sutured freehand in the subcoronary position.[16] Ionescu *et al* in Leeds mounted fascia lata and then pericardium on a frame with a sewing ring to facilitate implantation.[17] Lower *et al* investigated the potential for autogenous pulmonary valve aortic replacement in 1960, when they experimentally implanted pulmonary valve cusps in the descending thoracic aorta.[18]

Meanwhile, Duran and Gunning transferred their attention to preservation of heterograft (pig) valves. On 23 September 1964 they implanted the first stent-mounted porcine valve into a patient. Their experimental work with insertion of freeze-dried pig aortic valves in the descending thoracic aorta of dogs was published in 1965 but did not mention their clinical case.[19] In 1965 Binet *et al* in Paris presented their early experience of formalin preserved frame mounted heterografts and acknowledged Gunning's contribution.[20] Binet also worked with stentless aortic valve heterografts but the ease of implantation of frame mounted valves rapidly superseded freehand stentless techniques.[21] In 1967 Ross described pulmonary autograft replacement of the aortic valve in patients, a courageous advance before the era of cardioplegic arrest.[22] Ross never shared the view that the pig closely resembles the human and continued to pioneer the use of the aortic homografts and the pulmonary autograft throughout his career.

Aspects of surgical technique

There are several reasons why the Ross operation has not been widely adopted. The operation is complex and commits the surgeon to a long double valve operation, whereas a stented prosthesis can be inserted in a third of the time.[23] The early morbidity and mortality were substantial during the learning curve.[24] With improved surgical methods this is no longer so. The operation is applicable to most patients with aortic disease and provides a durable non-antigenic valve free from thromboembolic, bleeding, or degenerative complications.[3]

The pulmonary root is excised, taking care not to damage the left anterior descending coronary artery or its first septal branch, which lie close to the posterior aspect of the valve. The autogenous pulmonary root is a viable structure that will grow in the developing child.[25] For this reason it is left in a pool of blood in the pericardium rather than being transferred to a pot of saline. The pulmonary valve and artery are replaced with an aortic or pulmonary homograft. Then the viable pulmonary valve is used to replace the diseased aortic valve by either aortic root replacement or intra-aortic subcoronary insertion.[26] Because the pulmonary root is very thin, bleeding is a risk. Recent modifications of the Ross method have addressed this pitfall. The Elkins group in Oklahoma insert the pulmonary cylinder using a "root inclusion" method.[4] This implants the pulmonary root within the native aorta but preserves the circumference of the pulmonary outflow. Holes are made in the pulmonary arterial wall to accommodate the native coronary ostia. This modification prevents distortion of the commissures, provides external support for the distensible annulus, and limits bleeding. Pacifico *et al* use a circumferential wrap of bovine pericardium to support the distensible root and reduce the risk of bleeding.[27] These modifications are associated with reduced hospital mortality (< 2%) and infrequent aortic regurgitation.

Clearly the Ross procedure requires time, judgement, and skill. Increasing use has been stimulated by safer cardiopulmonary bypass, improved myocardial protection, and free availability of homograft valves. It is now used in patients aged from one day to 70 years.[28]

Haemodynamics, durability, and clinical outcome

All series have an early reoperative rate (up to 5%) for aortic regurgitation.[3 4 29] This is due to imperfect implantation or autograft patient mismatch where the annulus is large and the ascending aorta funnel-shaped. Transvalvar gradients are negligible and clearly better than for stented bioprostheses or mechanical valves. The incidence of autograft incompetence is less with the root replacement method and with external pericardial support.[4 27] Commissural malalignment is less of a problem with root replacement and when the autograft is implanted as a cylinder (as opposed to when one or more of its sinuses are scalloped).

In homograft surgery the valve is selected so that the internal diameter is 2 to 3 mm smaller than the internal diameter of the native aortic annulus. Ross considers that the pulmonary autograft can be used for aortic root or intra-aortic implantation despite diameter differences.[26] The native, untreated pulmonary arterial wall is so distensible that the elasticity compensates. Elkins advises against a mismatch between the autograft and the aortic annulus and considers that the Ross procedure is contraindicated when the aortic annulus is >27 mm in diameter.[4] The quality and strength of the pulmonary arterial wall are greater in children and young adults and in those who have undergone previous cardiac surgical procedures.[29] These subsets may be better suited to the use of an unwrapped autograft for root replacement.

Matsuki *et al* reporting Ross's patients (241 in 21 years) cite bacterial endocarditis and technical failure as the main reasons for reoperation.[3] Prolapse of the non-coronary cusp and detachment of sutures at the upper and lower margins of the graft were the predominant cause of incompetence. Reoperation because of primary tissue degeneration is rare (0·09% a year) and calcification can be identified only histologically. At reoperation prolapsing leaflets can sometimes be resuspended.

In Ross's early experience the actuarial freedom from reoperation was 50% at 20 years. About 20% of patients required reoperation for right ventricular outflow reconstruction but this was predominantly in patients with fascia lata or pericardial valved conduits.[3] The durability of aortic and pulmonary homografts in the right ventricular outflow tract is excellent. Calcification in right sided homografts is largely confined to the graft wall, the valve itself showing a remarkably low incidence of calcification and degeneration. Saravaki *et al* documented the fate of aortic homografts used for right ventricular outflow reconstruction after aortic and mitral valve replacements with pulmonary autografts.[30] The incidence of homograft wall calcification was only 27% for these patients in contrast to 92% for patients with right sided homografts in cyanotic congenital heart disease. This is partly accounted for by the younger age of patients with congenital disease and the presence of pulmonary hypertension. Ross now advocates replacement of the pulmonary valve with a stored pulmonary homograft, the wall of which is thinner and has even less potential for calcification.

Thromboembolism does not occur with the pulmonary autograft so that anticoagulation is not required at any stage of treatment. There is also increasing evidence that the valve grows with the patient. Elkins has recorded progressive increase in size of the autograft in children. This is proportional to the rate of growth and is unlikely to be caused by the propensity to stretch.[5] Enlargement does not result in aortic regurgitation and autografts with mild regurgitation postoperatively may become fully competent in time.

The future

The long-term functional results of aortic replacement with the pulmonary autograft are excellent and support the continued use and expansion of the method. Long-term event-free survival is clearly better than for any other category of aortic valve replacement, including the allegedly viable freehand-sewn, antibiotic-preserved aortic homograft or the "homovital" homograft from a transplanted heart.[31] At reoperation for right ventricular homograft degeneration, the autograft remains thin, pliable, and resembles a normal aortic valve.[24] With developing expertise and confidence the pulmonary autograft has been applied to surgery for rheumatic disease and for infection of the aortic root caused by native and prosthetic valve endocarditis.[32 33] Early experience suggests that the vital tissue is more conformable and resistant to infection than the aortic homograft. The outcome has been satisfactory despite the complexity of the operation in patients with an increased risk of abnormal bleeding.

Currently the overall hospital mortality for aortic replacement with a stented mechanical or bioprosthetic device is less than 2%. In young adults hospital mortality is negligible. In experienced hands the risks of pulmonary autograft procedure are similar but most surgeons are not willing to accept additional mortality during the learning

curve for what usually amounts to a double root replacement operation. There is now a registry for the Ross procedure to evaluate long-term outcome.[28] Excluding Ross's own patients, fewer than 500 patients have benefited from this operation to date and fewer than 100 surgeons worldwide have performed the operation.

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