Chapter 7

Valved Conduits Right Ventricle to Pulmonary Artery for Complex Congenital Heart Defects

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1. Introduction

The surgical implantation of a valved conduit to establish the continuity between the right ventricle and the pulmonary artery made possible the repair of a huge variety of complex congenital heart defects.

Diagnoses included tetralogy of Fallot, pulmonary atresia with ventricular septal defect, truncus arteriosus, transposition with ventricular septal defect and pulmonary stenosis or atresia, and various forms of double outlet right ventricle, ventricular septal defect, with or without pulmonary stenosis (1-7).

Right ventricle to pulmonary artery valved conduits have also been used in the pulmonary autograft replacement (Ross procedure) (8,9).

Various types of prosthetic and biological valved conduit have been used through the last decades, generally with satisfactory early hemodynamic performance, but most have been abandoned because of unsatisfactory long-term results.

Since any type of valved conduit utilized for clinical application present with some problem or complication in the long-term observations, the search for the ideal conduit is still ongoing.

For the decision making process among the various valved conduits currently available for surgical implantation, several options have been to taken into consideration regarding the type of conduit.

2. Types of biological valved conduits

2.1. Dacron valved conduits

Prosthetic Dacron conduits with incorporated a biological valve, porcine, bovine, or constructed with heterologous pericardium, have been used in the early period of this type of surgery (4-7,10).

The main advantage of this type of conduits was the off the shelf availability in a complete range of sizes, which made their use very attractive and practical.

The medium term results of Dacron valved conduits were complicated by failure of the conduits due to two main reasons (5-7,10-18):

a. the rapid development of thick pseudointima, causing conduit obstruction;
b. the rapid calcification of the glutaraldehyde preserved porcine valves, particularly in young children.

The combination of pseudointima formation and valve calcification resulted in conduit obstruction substantially reducing the freedom for conduit replacement, even in children where large size conduit had been implanted.

In favor of this type of valved conduits remained the slow and easy to detect progression of conduit stenosis, allowing timely plan of conduit replacement, facilitated by the easy shelling out of the covering pseudoadventitia, with a relatively low risk operation.

More recently aceptable long-term results have been reported with Dacron porcine valved conduits used for the right ventricular outflow tract reconstruction, particularly in patients with limited pulmonary vascular bed and high pulmonary artery pressures (19). Even in this reported positive experience the main limit of these conduits remained their rigidity, reducing the suitability for neonates and small infants.

2.2. Aortic and pulmonary homografts

After the first report of Rastelli on 1965 (1), Ross on 1966 introduced the use of the aortic valve with aortic root and ascending aorta to obtain the continuity between right ventricle and pulmonary artery with a biological valved conduit (2).

The homografts introduced by Ross were harvested from human cadavers, generally within 24-48 after death; after dissection they were treated for few days with antibiotic solution and then stored for up to 4 weeks at 4°C in either a balanced salt solution or in a special tissue culture medium (2).

Two changes were subsequently introduced in the homografts preparation:

a. homografts were sterilized by high-power irradiation
b. homografts were freeze dried

The combination of the two above techniques resulted in cells death, with severe damage to the collagen of the homografts, and particularly to the valve leaflets, resulting in conduit

valve stenosis. As a result the use of frozen conduit with the above preparation has been abandoned, and few hospital in Europe continued to use fresh, antibiotic sterilized conduit (20,21).

Unfortunately became evident from clinical studies that homografts stored at 4°C were gradually losing cellular viability and tissue integrity; because of these reasons the fresh homografts had to be discarded 4 to 6 weeks after preparation because not suitable for clinical utilization.

The consequence was a homograft shortage, particularly for the smaller sizes, required for implantation in small children, due to the limited number of donors.

Major progress in the utilization of homografts has been the introduction of cryopreservation technology in the preparation, particularly with the controlled freezing to the temperature of liquid nitrogen (-196°C). This method allowed a large scale introduction of homografts in the clinical practice, despite issues related to the cellular viability of donor cells in the maintenance of the homografts durability (22-26).

The results provided by homografts on medium and long-term clinical observations were quite good, and nowadays these results are still used as comparison with any other type of biological valved conduit introduced in clinical practice (27-28).

Nevertheless the utilization of homografts present with the following issues:

a. the choice between aortic and pulmonary homografts
   The arterial wall of pulmonary homografts is thinner (60% thickness) than the wall of aortic homografts, and the elastin concentration is less.
   Because of this combination rapid dilatation of pulmonary homografts has been reported when implanted in children with pulmonary hypertension, and therefore were exposed to systemic pressure (22,23).

b. the rapid outgrowth of the conduit when implanted in infants and small children
   Longitudinal growth can result in lengthening and narrowing. Severe degree of calcification, due to he accelerated calcium metabolism in children, can reduce the size of the homograft lumen, and also the valve leaflets can rigid and stenotic, and also calcified (29-31). This can oblige to an early conduit replacement, even if very long-term observations have been reported, up to 21 years (32).

c. the reduced availability
   Homografts are not always available worldwide, particularly in the small sizes frequently requested for implantation in infants and small children. The technique of bicuspidalization of adult size homografts has been utilized in order to produce homografts of small size, with decent results even recently reported at long-term follow-up (33).

d. the immunitary reaction
   In most children where an homograft gas been implanted, humoral antibodies developed against human leukocyte antigen specific to the transplanted tissue. Host

antigen recognition and antibody development may be linked to early tissue calcification and structural valved deterioration with valved conduit failure (34-36).

2.3. Bovine jugular vein

The bovine jugular vein (Contegra®, Medtronic Inc., Minneapolis, MN), containing a trileaflet valve, was introduced into clinical practice as an alternative to the use of homografts in 1999 and has provided encouraging results in several reported clinical series, with follow-up reaching more than 10 years (37-45).

Recognized advantages of the bovine jugular vein are:

a. structural continuity between the wall of the jugular vein of the conduit and the valve leaflets, which provides optimal hemodynamics because of the ideal effective orifice area
b. unlimited "off-the-shelf" availability in sizes from 12 to 22 mm diameter, representing a good alternative to the homograft shortage, particularly in the smaller sizes
c. availability of a long length at both inflow and outflow that obviates the need for either proximal or distal augmentation; this facilitates conduit tailoring and positioning which helps to avoid potential distortion and sternal compression
d. exceptional reports of antigenic reaction, due to glutaraldehyde fixation

In contrast to the good clinical results obtained in several institutions (37-45), a disturbing sequence of publications reported stenosis at the level of the distal anastomosis of the conduit, with proximal conduit dilatation, aneurysm or pseudo-aneurysm, in between 6 and 50% of patients (39,40,42,46-54).

The problem of conduit dilatation related to obstruction at the distal anastomosis has been reported as a specific complication of the bovine jugular vein (46-54).

The following mechanisms were recognized as potential causes of distal stenosis:

a. presence of hypoplasia and/or distal stenosis of pulmonary artery branches
b. discrepancy in size between conduit and pulmonary artery
c. surgical technique
d. local immunologic/inflammatory reaction
e. local peel formation
f. thrombosis
g. a combination of two or more of the above (55).

The impact of the surgical technique has previously been studied using Computational Fluid Dynamics comparing two types of distal anastomosis: the conventional end-to-end "*circular*" anastomosis versus the oblique "*elliptical*" anastomosis with the incision extended on to the anterior aspect of the left pulmonary artery and the distal end of the conduit obliquely tailored.

The study confirmed a larger cross sectional area in the "*elliptical*" compared to the "*circular*" type of anastomosis along with more homogeneous velocity, pressure and shear stress distribution (55).

These results suggested that the "elliptical" anastomosis might reduce the incidence and degree of distal stenosis, particularly for smaller conduits.

We have therefore adopted this technique for the distal anastomosis, and in addition careful rinsing (5 minutes X 3 in different saline solutions) of the bovine jugular vein before implantation to clear the glutaraldehyde to reduce the inflammatory reaction, and avoidance of oversized conduits to reduce the discrepancy between conduit and distal pulmonary artery size (45).

Using this protocol the distal conduit stenosis has became a rare observation in our experience even with the smaller conduits (45).

Early calcification of biological valved conduits is frequently reported with homografts, particularly the smaller size conduits implanted in infants or small children in the first few years of life (30,37).

In our experience early conduit calcification causing hemodynamic consequences was never observed, confirming our own previous observations and those of other researchers (39,40,42,45).

We speculate that rinsing the glutaraldehyde off before bovine jugular vein implantation reduces the calcium deposition and then prophylactic antiplatelet treatment (Aspirine 5 mg/kg/day), started immediately after surgery and continued at least for one year, may play a role.

2.5. Tissue engineered decellularized allografts

The most recently introduced biological valved conduits are the decellularized valved conduits.

The principle for the preparation is the decellularization process applied to allografts tissue to reduce the antigenicity. The mechanism of decellularization result in the removal of all native cells from the collagen tissue of the extracellular matrix, with only the collagen and elastin remaining within a structural integrity maintained. The removal of the cellular material should reduce or eliminate the immunologic response and leave the functional vascular matrix available for autogenous remodeling. The progressive migration of the recipient-specific cells into the matrix nay eventually make the graft indistinguishable from other endogenous tissues (56-61).

Different techniques have been used for decellularization, as well as they have been applied to either fresh or cryopreserved valve matrix.

The clinical reports so far were limited to a relatively short follow-up, and therefore longer periods of observation are required before considering this type of conduits as a reliable alternative to the conventional biological valved conduits.

3. Size of the biological valved conduits

The significantly higher incidence (29.4% versus 3.1%, P<0.0005) of conduit failure observed with smaller (12 and 14mm) compared to larger (16 to 22mm) bovine jugular vein conduits was directly correlated to the age and body weight at implantation, and was due to the patient outgrowing the conduit (45).

This is a recurrent problem observed with any type of biological valved conduit implanted in small patients, when a difficult balance has to be reached between the need to limit the size of the ventriculotomy, the space available in the mediastinum (particularly in heart defects with anterior aorta), and the instinct to implant the largest possible conduit to avoid early reoperation (30,37,45,62,63).

It has been reported that implantation of oversized pulmonary valved conduits doesn't improve the durability even in infants at high risk of somatic outgrowth (30,37,64).

Since it has been demonstrated that sizing the valved conduit with a Z-score between +1 and +3 minimizes both the post-operative peak pressure gradient through the conduit and the progression of conduit valve regurgitation (64), it is reasonable to implant a biological valved conduit with a Z-score between +1 and +3 in all patients under 2 years of age.

With this regard the choice of relative small size valved conduit is limited by the reduced availability of homografts in small sizes.

4. Conclusions

The ideal biological valved conduit to establish right ventricle to pulmonary artery continuity for the surgical treatment of complex congenital heart defects doesn't exist yet.

Particularly when the operation has to be performed in infants and small children, at least one reoperation has to be planned to replace the original conduit with a larger size conduit.

Alternative surgical options are taken in consideration, like the use of a non-valved conduit implantation to delay the conduit failure due to progressive stenosis and dysfunction of the conduit valve (65-70).

The data available in the literature show that, on a midterm basis, the use of non valved conduit may decrease the need for re-operation for right ventricular outflow tract stenosis and may promote an adequate growth of the pulmonary arteries in selected congenital heart defects, like truncus arteriosus (65-70).

In infants and smaller children where a valved conduit is required, the choice of homografts is limited by the reduced availability of small sizes, and therefore other types of biological valved conduits are utilized more frequently. Because of this reason, the surgeons still preferring the homografts have used the technique of bicuspidalization of adult size homografts to produce homografts of small size (33).

In older children and young adults, since the availability of homografts is extremely variable from country to country, at the moment there is the possibility of deciding among various alternative options, with biological valved conduits available off the shelves in all range of sizes.

At the end the choice regarding type and size of conduit depends upon the mismatch between the congenital heart defect of the specific patient, the local availability of conduits, and the personal experience of the individual surgeon.

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