Annals of Thoracic Surgery
Volume 96(1), pp. e25-e27
July 2013
Accepted 8 April, 2013

Guidelines for sizing pericardium for aortic valve leaflet grafts

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Abstract

Surgical repair of the aortic valve using leaflet grafts made from pericardium has been shown to be a viable option, particularly in children, in whom valve replacement has strong disadvantages. We present guidelines for sizing treated autologous pericardium to fabricate a leaflet graft for single leaflet replacement. Both our clinical experience and experimental evidence indicate that effective repairs are best achieved using a semicircular graft with diameter 10-15% greater than the sinotubular junction diameter in diastole. We also provide a simple formula to allow adjusting these guidelines to account for variation in valve geometry and tissue properties.

Introduction

Reconstruction of the aortic valve using pericardium has been reported since the 1960's, however it remains technically challenging. The structures of the valve are considerably distended under physiological conditions relative to the intraoperative (unpressurized) state, and to create an adequate repair, the surgeon must account for how much the aortic root, native valve leaflets, and graft material will distend when the aorta is closed and blood flow restored. Reliable guidelines for sizing pericardium leaflet grafts could widen adoption of these repair procedures.

Various techniques have been reported for determining the dimensions of pericardium grafts for leaflet replacement. One approach is to base the graft dimensions on intraoperative measurements of the native leaflets [1]. However, leaflet tissue is highly distensible, making it difficult to make reliable leaflet measurements. Furthermore, the relationship between intraoperative dimensions and in vivo requirements is not straightforward. To avoid these pitfalls, methods have been proposed for fabricating leaflet replacement grafts based on preoperative echocardiographic measurements of the aortic root [2,3]. Both of these methods, however, rely on specialized templates or molds to fabricate the grafts.

At our institution, we have an interest in aortic valve repair involving single-leaflet replacement, a common procedure in children undergoing late aortic valve repair following balloon dilatation for congenital aortic stenosis. In this report we describe our surgical technique for aortic valve single leaflet replacement using autologous pericardium. We report a simple graft sizing relationship used when the root and remaining leaflets are relatively normal/healthy, and we suggest a formula that takes graft properties and valve geometry into account when root geometry or commissure location is abnormal.

Technique

After sternotomy, a roughly 3-4 cm square patch of pericardium is excised, pinned flat (but unstretched) on sterile cardboard, fixed in 0.625% glutaraldehyde for 3-5 minutes, then rinsed (3 times for 3 minutes each) in saline. The initial step requires assessment of the position and height of commissures and leaflets. Commissure position is noted independent of commissure height or leaflet fusion. If there are three commissures, we have utilized a single leaflet replacement technique where the deficient leaflet, usually the anterior, is excised and replaced by pericardium or similar material. For the leaflet replacement, a semicircle is cut from a region of the patch with approximately uniform thickness and fiber direction, with the semicircle oriented so that its straight edge aligns with the predominant fiber direction. Based on our clinical experience with aortic valve reconstruction in 56 patients over two years, when the aortic root contains three discernible commissures, the diameter of the semicircle should be 10-15 % greater than the diameter of the sinotubular junction in diastole from echo, with an additional 2 mm added to account for a 1 mm suturing margin around the semicircumference (Fig 1). In cases where a commissure height is abnormal, the new leaflet is sewn onto the aortic wall in the same direction as the rudimentary commissure.

Effect of Graft Properties and Valve Geometry

While our graft sizing guidelines are based primarily on clinical experience, expressing them in a more general form in terms of valve geometry and tissue properties can provide useful insights into valve repair. When a normal aortic valve is closed at peak diastole, the free edge of a single leaflet is both stretched and pulled downward from the commissures. The resting (unstrained) width, W, of a leaflet can be estimated from the diameter of the sinotubular junction (STJ) at peak diastole, d, the degree of stretch undergone by the leaflet free edge at peak diastole, λ, and the downward angle of the free edge, φ, using the formula:

$$W = \frac{d}{\lambda cos\phi} \quad (1)$$

(Fig. 2). From published anatomical studies, angle φ has been reported to be approximately 35º [4], in agreement with our unpublished observations. Given the expected stretch, λ, of the graft free edge for a given graft material, the graft width (diameter) can be computed for a given STJ diameter, d. For example, the free edge of our pericardium graft elongates by approximately 10% ($\lambda = 1.10$) under physiological loads, so Eq. 1 results in a predicted leaflet graft width of between 10 and 15 % greater than the STJ diameter in diastole. This agrees with the guidelines at which we have arrived based on clinical experience.

Comment

Other groups have published methods for sizing leaflet grafts fabricated from pericardium [2,3,5]. While their sizing guidelines are not all presented in the same form as ours, they all translate to sizing the graft width to be somewhat larger than the STJ diameter in diastole. A similar guideline has been reported for sizing aortic valve cusp extensions, with graft width equal to 1.15 times STJ diameter [6]. Our simple 10-15 % sizing guideline is limited in that it only applies for grafts fabricated from pericardium with the same properties as that used in our procedures and for valves in which the aortic root and remaining leaflets are relatively normal. The advantage to presenting our graft sizing guideline in a slightly more complex form (Eq. 1) is that it allows graft size to be estimated for cases where graft properties and/or valve geometry vary. For example, if the graft is made from material that does not stretch appreciably under load (e.g., extracellular matrix patches), we can use Eq. 1 with $\lambda = 1.0$, resulting in a graft width estimate of 1.22 times STJ diameter. Or if the leaflet free edge angle in diastole is greater than normal (possibly due to a calcified root or prior valve sparing surgery), graft width can again be estimated using Eq. 1 and the larger value for φ as measured on preoperative echo.

The agreement between clinical experience in graft sizing and the predictions of Eq. 1 is important because it suggests a working understanding of factors that influence the behavior of aortic valves that have been reconstructed with pericardium. In fact our recent ex vivo experiments and computer simulations of aortic valve repair [7] further corroborate our clinical findings and increase our confidence in the accuracy of our computational model of valve repair. A future challenge is to predict reliable valve repair guidelines on a patient-specific basis in cases where valve anatomy is abnormal (e.g., bileaflet or unicommissural) or where tissue properties are altered due to leaflet or root pathology.

Supported by grants R01 HL073647 and R01 HL110997 from the National Institutes of Health.

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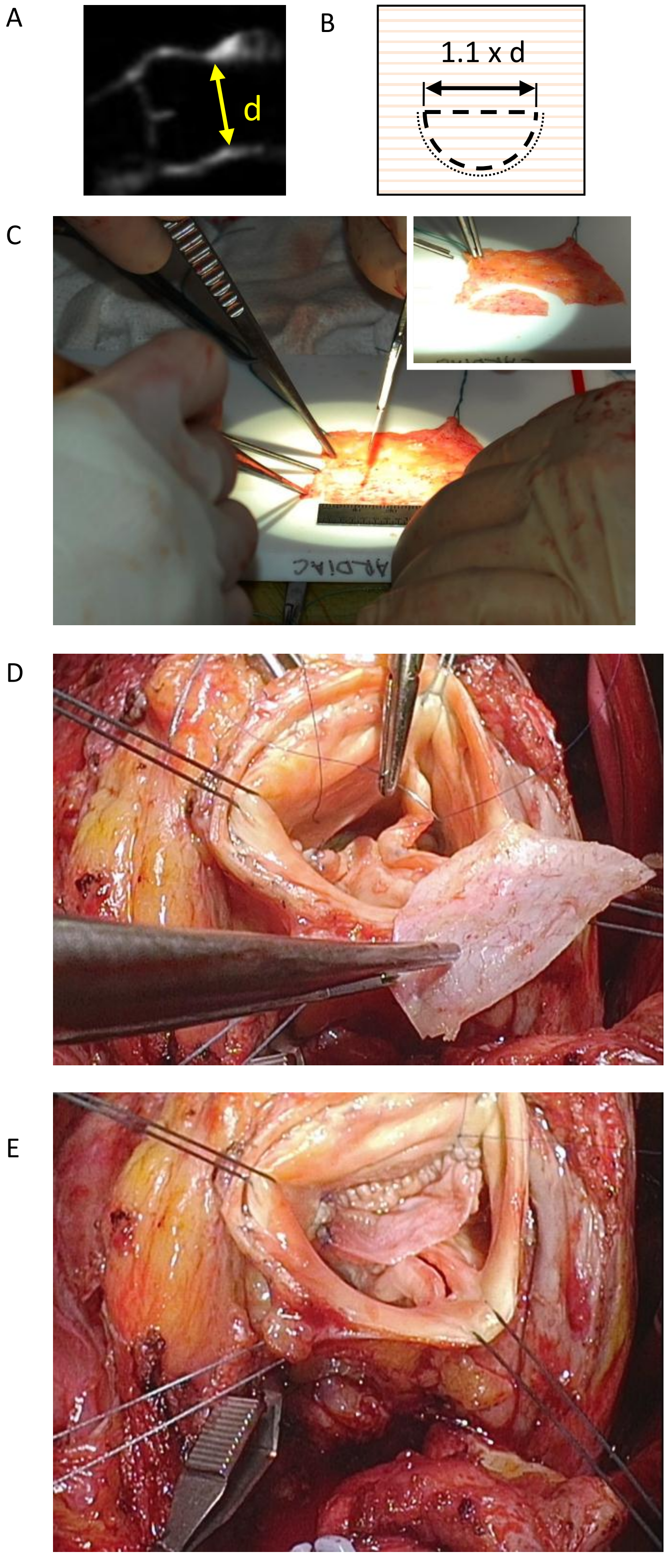

Fig. 1. A) Diameter of sinotubular junction, d, is measured from echocardiographic image. B and C) Graft is cut from treated pericardium in the shape of a semicircle with diameter approximately 10 % greater than d, and a 1 mm margin is added along the semicircumference for suturing (dotted line). D and E) Graft is sewn in with a running suture.

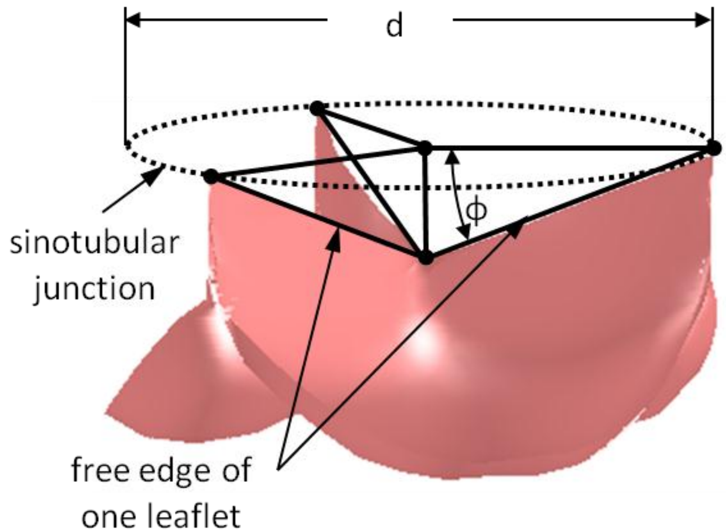

Fig. 2. Measurements used to describe aortic valve in diastole.