A normogram to anticipate dimension of neo-sinuses of valsalva in valve-sparing aortic operations

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Abstract

Objective: The aim of the present study was to define a method to pre-determine the correct size of neo-sinuses of Valsalva in the reimplantation type of valve-sparing aortic operation. Methods: The objective was achieved in three steps: (1) evaluation in the healthy population, of the normal size of sinuses of Valsalva expressed as the area surrounding fully opened aortic cusps, the so-called beyond leaflets area; (2) elaboration of a normogram by which, given a known annular diameter, it is possible to select the appropriate graft size to obtain a normal beyond leaflets area; (3) validation of the normogram by comparing, in a population of 20 patients undergoing a valve-sparing procedure, the predicted and observed beyond leaflets area. Results: The following values for beyond leaflets area were observed: mean normal 320.6 ± 120.6 mm², mean predicted 355 ± 63.2 mm², mean observed 364.7 ± 72.8 mm². No significant differences were obtained for predicted versus observed values. Regression analysis showed a linear distribution with an r value of 0.95. Conclusions: We proposed a simplified approach for sizing of the neo-aortic root in the reimplantation type of valve-sparing aortic operation focussed on the size of sinuses of Valsalva. Our normogram showed to be reliable in anticipating beyond leaflets area. It can be helpful in avoiding the selection of an undersized or excessively oversized graft.

Keywords: Aortic valve-sparing operation; Sinuses of Valsalva; Aortic valve reimplantation; Aortic root aneurysm; Aortic regurgitation; Aortic root sizing

1. Introduction

The aortic valve-sparing operation has become the standard for aortic root dilatation with preserved aortic leaflets. Both the 'remodeling' operation described by Sarsam and Yacoub [1] and the 'reimplantation' technique described by David and Feindel [2] have provided excellent clinical results.

The aortic valve and the aortic annulus, in the original description of the reimplantation technique [2], are sutured inside a Dacron graft, this prevents further dilatation of the aortic root, sinuses of Valsalva, however, are lost.

In the last decade, the function of sinuses of Valsalva has been emphasized and modifications have been proposed to include neo or pseudo-sinuses of Valsalva in the repair [3-8].

Normal shape, size and function of the aortic root have been elucidated [9,10] and methods suggested to select the optimal tubular graft size for a given patient [11-15].

In the present study, we sought to define a new method to pre-determine the correct size of neo-sinuses of Valsalva in the reimplantation technique.

2. Material and methods

2.1. Normal size of sinuses of Valsalva

To define aortic root dimensions in a normal population, 50 healthy subjects (22 males, age 38.5 ± 10.9, BSA 1.76 ± 0.18 m²) underwent trans-thoracic echocardiography using a Hewlett-Packard Sonos 5500 system (Hewlett-Packard, Andover, MA) with a 2.5 MHz ultrasound transducer. Parasternal long axis and short axis views were used. The following measures were recorded: aortic annulus diameter systolic (ADS), aortic annulus diameter diastolic (ADD), maximal systolic aortic diameter at sinuses level (SDS), maximal diastolic aortic diameter at sinuses level (SDD), sino-tubular junction diameter systolic (STJS), sino-tubular junction diameter diastolic (STJD). The equation: circle surface area = π × circle diameter² / 4 was used to...
calculate BLA by the following formula

\[
BLA = \pi SD^2/4 - \pi AD^2/4
\]

where \( \pi SD^2/4 \) is the systolic section area at sinuses level and \( \pi AD^2/4 \) is the systolic surface included between fully opened aortic leaflets. This formula is based on the assumption that trans-valvular aortic flow has a cylindrical shape. Each measure was expressed as the mean ± standard deviation of three determinations, both absolute and indexed values were recorded.

In order to avoid interference of sex distribution, the population was divided in two groups: males (22 cases, age 40.1 ± 11.5, BSA 1.92 ± 0.11 m\(^2\)) and females (28 cases, age 37.3 ± 10.6, BSA 1.64 ± 0.12 m\(^2\)).

### 2.2. Normogram elaboration

The theoretical BLA resulting from any possible combination aortic annulus size–ascending aortic graft diameter was calculated by the following formula

\[
Graft BLA = \pi GD^2/4 - \pi AD^2/4
\]

where GD is the Graft diameter and AD is the annulus diameter, including the formula annular sizes ranging between 19 and 31 mm and a graft diameter ranging from Graft diameter = annular size + 1 mm to Graft diameter = annular size + 13 mm. Results were expressed as a normogram: annular diameters were plotted against different grades of over sizing of the graft expressed in millimeter from 1, graft diameter 1 mm more than the annulus, to 13, graft diameter 13 mm more than the annulus. Four different BLA ranges of 200 mm\(^2\) each were defined as colored areas (Fig. 1). Every single intersecting point on the normogram represents the BLA for a given annulus and a given graft. According to our 'healthy population' data, the blue area defines a BLA too small to accommodate aortic leaflets, the yellow area represents the normal BLA range, the orange area includes the 'upper limit' population, the red area represents a BLA clearly over normal range.

### 2.3. Operative technique

Hypothermic cardiopulmonary bypass and intermittent antegrade or retrograde hyperkaliemic blood cardioplegia were used in all cases. The aneurismal ascending aorta was cannulated for arterial return and, after circulatory arrest, by inserting a cannula into the ascending aortic prosthesis, antegrade perfusion was re instituted in elective cases. In dissection cases, axillary artery cannulation was used for arterial return. The aorta was clamped and opened and anatomy of aortic leaflet assessed, aortic sinuses were excised leaving a 3-5 mm rim of aortic wall above the hinge line of the leaflets and the three commissures. Coronary buttons were isolated on a Carrel patch. Commissures were suspended by U shaped 4/0 polypropylene sutures. Horizontal mattress sutures were passed below the aortic leaflets from the inside. If an annulus size reduction was planned, these sutures were pulled to crimp annular tissue. When a nice valve coaptation and no folds on the leaflets was observed annular diameter was measured with an Hegar’s dilator or a by a standard prosthetic valve sizer.

Once an annular size was determined, the conduit was chosen based on our normogram selecting a combination annulus-graft included in the yellow area for patients with normal leaflets and in the orange area for patients with elongated aortic leaflets and increased annulus to commissure length.

Sino-tubular junction diameter was planned to be around 10% more than the annulus, in practice 2 mm more than the annulus or the next prosthetic valve sizer. The mattress sutures were then passed at the base of the conduit and tied down on the same Hegar’s dilator or prosthetic aortic valve sizer used to measure the annulus in order to avoid excess aortic annulus size reduction. This part of the technique is similar to that described by Svensson [13] except for the fact that annular size is not normalized for BSA but dictated by aortic leaflets size. Aortic wall remnants were fixed to the conduit by three continuous 5/0 polypropylene running sutures starting at the nadir of each sinus. A new sino-tubular junction was obtained by fixing the three commissures inside the conduit at the appropriate level. Coronary ostia were reimplanted by 6/0 polypropylene continuous sutures. At this time 4/0 polypropylene plication sutures were applied on the conduit to obtain the desired sino-tubular junction size. In all cases, the distal anastomosis between the conduit and the aorta was performed under circulatory arrest (8-14 min, mean 10.8 ± 1.6 min) at a temperature ranging from 25 to 28 °C by a continuous 4/0 polypropylene suture. After a short period of wash-out retrograde cerebral perfusion, antegrade circulation was restarted, rewarming completed and operation concluded as usual.
Table 1
Normal values in healthy population

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measured or predicted (observed values)</th>
<th>Range</th>
<th>Index (m²)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic annulus diameter (mm)</td>
<td>22.3 ± 1.17 (22.0 ± 1.17)</td>
<td>21-25 (20-24)</td>
<td>12.5 ± 0.89 (12.3 ± 0.95)</td>
<td>NS</td>
</tr>
<tr>
<td>Tube graft diameter (mm)</td>
<td>30.8 ± 1.36 (30.8 ± 1.36)</td>
<td>28-34 (28-34)</td>
<td>17.2 ± 1.4 (17.2 ± 1.4)</td>
<td>NS</td>
</tr>
<tr>
<td>Aortic annulus area (mm²)</td>
<td>391.4 ± 41.3 (382 ± 48.8)</td>
<td>346.2-490.6 (314-452)</td>
<td>218.7 ± 23.3 (213.3 ± 26.8)</td>
<td>NS</td>
</tr>
<tr>
<td>Tube graft area (mm²)</td>
<td>746.0 ± 66.4 (746.0 ± 66.4)</td>
<td>615-907 (615-907)</td>
<td>418 ± 49.4 (418 ± 49.4)</td>
<td>NS</td>
</tr>
<tr>
<td>STJ diameter (mm)</td>
<td>24.3 ± 1.17 (24.7 ± 1.45)</td>
<td>23-27 (22-28)</td>
<td>13.39 ± 0.9 (13.8 ± 1.17)</td>
<td>NS</td>
</tr>
<tr>
<td>BLA (mm²)</td>
<td>355 ± 63.2 (364.7 ± 72.8)</td>
<td>260-458 (254.3-489.8)</td>
<td>199.5 ± 42 (204.8 ± 47.2)</td>
<td>NS</td>
</tr>
</tbody>
</table>

ADS, aortic annulus diameter systolic; ADD, aortic annulus diameter diastolic; SDS, sinuses diameter systolic; SDD, sinuses diameter diastolic; STJS, sino-tubular junction diameter systolic; STJD, sino-tubular junction diameter diastolic; BLA, beyond leaflets area; BSA, body surface area.

2.4. Normogram validation

Twenty patients (16 males, mean age 56.9 ± 9.3 years, mean BSA 1.79 ± 0.12 m²) undergoing a valve-sparing operation between January 2002 and January 2003 were included in the study. Eighteen patients were operated on during the study period and two had been operated on previously (Table 2). Their mean age was 56.9 ± 9.3 years, their mean height was 172 ± 8 cm, and their mean weight was 72 ± 10 kg. In 12 cases the root was replaced with a homograft (Table 3). All had a tricuspid aortic valve with a regurgitation grade ranging from 2+ to 4+ (mean of 2.6 ± 0.59) and a mean ejection fraction of 48.5 ± 6.8. In all of them, the reimplantation technique was applied according to the described technical details.

At a mean follow-up of 8.75 ± 2.6 months (range 4–14 months) all patients underwent echocardiography. Aortic root dimensions were acquired in parasternal long axis and short axis views or by trans-esophageal echo when the thoracic acoustic windows were not satisfactory. Measures were taken at the following levels: annulus diameter systolic (ADS), annulus diameter diastolic (ADD), sinus diameter systolic (SDS), sinus diameter diastolic (SDD), sino-tubular junction systolic (STJS), sino-tubular junction diastolic (STJD). Results were expressed as the mean ± standard deviation of three determinations, both absolute and indexed values were recorded. BLA was calculated by the following formula:

Observed BLA = πGD²/4 – πADS²/4

where GD is the Graft diameter and ADS is the annulus diameter systolic.

2.5. Statistical analysis

Descriptive statistics are reported as the means ± SD for continuous variables. Comparison between groups was made with unpaired t-test for continuous variables and χ² or Fisher’s exact test for categorical variables. Regression analysis was used to correlate predicted and observed values.

3. Results

There were no deaths, no major cerebrovascular accidents. Follow-up was complete. Measurement of the aortic root in healthy subjects are reported in Table 1. Table 2 compares predicted measures of the aortic root obtained at operation based on our normogram versus values observed at follow-up visit. In our experience, aortic annulus diameter was 21 or 23 mm in 19/20 cases (95%); a 30 or 32 mm graft was used in 18/20 cases (90%). Mean tube graft oversizing grade was 8.5 ± 1.39 mm (range 7–11), indexed 4.78 ± 0.9 mm/m². A type A aortic leaflets coaptation was obtained in 19/20 cases and a type B in 1/20 while a trivial (1+) aortic regurgitation was observed in 4/20 cases, a mild (2+) aortic regurgitation in 1/20 cases and no regurgitation in 15 cases. At a mean follow-up of 8.75 ± 2.6 months (range 4–14 months), these results were confirmed by echocardiography.

Statistical analysis showed no significant differences in terms of body surface area between the healthy population and the study population. For the David operation high predictive value of our normogram was confirmed by the absence of any significant statistical difference between predicted and observed beyond leaflets area (Table 2). Regression analysis showed a distribution of data very closely fitting a line with an r-value of 0.95.

4. Discussion

The ‘eddy currents’ described in aortic sinuses by Leonardo da Vinci in a glass model of the aortic root [16]...
and recently demonstrated in vivo by Knitting [17] play a key role in aortic root function. As documented in the late 1960s by Bellhouse [18,19], the 'eddy currents' twirling inside sinuses avoid contact of aortic leaflets with aortic wall and promote smooth aortic valve closure. Sinuses of Valsalva also have the function to share with aortic leaflets diastolic stress during valve closure and to promote coronary blood flow.

In the last decade, many modifications of the original David's reimplantation technique have been proposed in an attempt to reproduce anatomy and function of the aortic sinuses. Recently De Paulis developed a prosthesis (Gelweave Valsalva; Sulzer Vascutek, Renfrewshire, Scotland) incorporating a self-expandable region obtained by a 90° rotation of the Dacron fabric corrugations with respect to the rest of the graft. With this prosthesis, it is easier to achieve sinuses with a shape very closely mimicking nature and a nice and smooth aortic valve opening and closure [20].

It has to be emphasized that prosthetic sinuses of Valsalva are not expandable or became stiff in the long run and probably they loose with time the capacity to share the stress with aortic leaflets or to promote coronary blood flow like in normal individuals. The only characteristics that they preserve over time are the shape, geometry and dimension which are responsible for a correct formation and streaming of the currents of Leonardo and drive a correct movement and thus durability, of aortic cusps.

Although a variety of techniques have been proposed for neo-aortic root sizing, we were not able to find studies looking at the extension of the area surrounding aortic leaflets. It is clear that small sinuses could be at risk of a systolic contact between aortic leaflets and the neo-aortic wall, it remains to be studied if sinuses bigger than 'normal' could be harmful for a correct function of the aortic valve or for coronary artery perfusion. What we can learn from clinical experience is that aortic leaflets in presence of dilated sinuses of Valsalva often show altered function, with resulting regurgitation and some gross anatomical anomaly due to turbulent flow.

Pethig [21] demonstrated that morphology of final aortic leaflets coaptation and grading of eventual residual aortic regurgitation has a strong impact on long-term durability of the repair. The competence of the aortic valve is therefore the key to a good result. Excess undersizing of the graft to prevent regurgitation or excess oversizing in order to obtain well represented sinuses of Valsalva may result in less than perfect results. Our normogram was elaborated in order to prevent these problems.

Our approach is centered on aortic leaflets size and combines experience and mathematics. The goal is to obtain an aortic root with a new annulus and new sinuses matched to leaflets size, not an absolutely 'normalized' aortic root. Qualitative appraisal of aortic leaflets coaptation after passing annular sutures is a matter of 'art' but can be acquired in a short time. Once a nice coaptation has been reached, the surgeon simply has to measure the annulus and refer to the normogram to select a tube graft included in the yellow or orange area depending on the degree of elongation of leaflets and commissures. Looking at the chart, most of the grafts selected in our experience are included in the border zone between the yellow and the orange area. This probably reflects our intention to find a compromise between well represented sinuses and a competent aortic valve.

The study has one major limitation: our 'predicted' values are measured on the flaccid arrested heart and probably are slightly underestimated. However, since no 'remodeling' patients are included in the study, dimensions of the annulus are fixed. The only variation in size throughout the cardiac cycle both for the annulus and the sino-tubular junction should be limited to the compliance of the tubular graft that is below 2%. In fact no statistically significant differences were observed between predicted and observed values for systolic annulus diameter, systolic sinuses maximal diameter, systolic STJ maximal diameter and BLA.

In conclusion, we propose a simplified approach for sizing of the neo-aortic root in the reimplantation type of valve-sparing operation focussed on the size of sinuses of Valsalva. Our normogram is not intended as a substitute for art or experience, however, since it has a good performance in anticipating BLA, it can be helpful in avoiding the selection of an undersized or excessively oversized graft.

References


Appendix A. Conference discussion

*Dr G. Wimmer-Greinecker* (Frankfurt, Germany): Could you tell us something about your technique of creating the neo-sinuses.

*Dr Maselli*: In this part of the study, the sinuses are created by oversizing the graft and reducing the size of the graft at the level of the annulus and at the level of the sinotubular junction.

So the annulus is measured first. And after passing the sutures at the annular level, the annulus is measured again, and is the baseline for referring to the chart. And then, a graft oversizing, which gives a normal beyond leaflet area, is selected in order to achieve normal sinuses.

*Dr Wimmer-Greinecker*: But you do this with three single stitches?

*Dr Maselli*: No. We have the usual subannular suture, and then the sinotubular junction is reduced with stitches at the level of commissures.