Midterm follow-up dynamic echocardiography evaluation after ascending aorta replacement and reimplantation of the aortic valve (David operation) in a matched control study

Giuseppe D’Ancona*, Renato Ciofalo, Domenico Biondo, Marco Follis and Fabrizio Follis

* Department of CT Surgery, Mediterranean Institute for Transplantation and Advanced Specialized Therapies (ISMETT), Palermo, Italy
b Division of Cardiology, ARNAS, Palermo, Italy

Received 25 June 2011; received in revised form 22 August 2011; accepted 25 August 2011

Abstract

OBJECTIVE: Dynamic performance of the aortic valve (AV) after ascending aorta replacement with reimplantation of the native AV (David) was investigated.

METHODS: We prospectively evaluated 17 patients who underwent David procedure. Rest/stress echocardiography follow-up was performed and results were compared with those of matched healthy controls.

RESULTS: There were no significant differences in terms of age, height, weight, BSA, left ventricular mass, left ventricular ejection fraction (LVEF) and tele-diastolic volume between the David and control group. At rest echocardiography, patients in the David group had a lower indexed aortic valve area (IAVA) (1.1 ± 0.2 vs. 1.5 ± 0.2 cm²/m², \(P < 0.0001\)), with comparable transvalvular gradients (TVG).

At maximal physical stress, although the IAVA in the David group was significantly increased from the rest values (\(P = 0.001\)), the difference with the control group persisted (David 1.4 ± 0.3 vs. Control 1.7 ± 0.2 cm²/m², \(P < 0.0001\)) maintaining similar peak TVG (David 13.6 ± 5.3 vs. Control 11.7 ± 4.5 mmHg, \(P = \text{ns}\)) and mean TVG (David 7.2 ± 3.0 vs. 6.2 ± 2.4 mmHg, \(P = \text{ns}\)). AV regurgitation in the David group was absent in five (29.4%), grade I in nine (52.9%) and grade II in three (17.6%) patients and remained unchanged during stress.

At multiple linear regression, David operation was inversely correlated to rest IAVA (OR = −0.4; \(P = 0.01\); CI: −0.7–0.1).

CONCLUSIONS: Although IAVA is significantly smaller after David procedure in comparison with matched controls, no pathological increase in TVG is noticed. A significant increase in the IAVA during physical stress documents the preserved pliability/elasticity of the aortic unit after David procedure preventing pathological increase in the TVG even during strenuous effort.

Keywords: David stress-echocardiography • Aortic valve area

INTRODUCTION

Description of valve sparing procedures by Yacoub in 1979 [1] and David in 1988 [2], respectively, has sparked tremendous interest in reparative techniques of the aortic valve (AV), somehow neglected up to that time in comparison with the mitral valve. As a result, the anatomy and physiology and the importance of the aortic root complex as a single unit have been clarified in detail. Despite the outstanding results reported in the literature [3, 4], however, the fate of the AV complex after remodelling or reimplantation procedures remains an object of much debate [5]. On the other hand, exercise echocardiography has become an important tool in revealing the dynamics of the valve and the ventricle and unmasking functional disabilities in patients who often adapt by reducing their physical activity [6]. In the light of these considerations we became interested in studying by means of echocardiography the behaviour of the AV complex after a reimplantation procedure, at rest and after exercise, in comparison with normal subjects.

MATERIALS AND METHODS

Twenty-one consecutive patients underwent a reimplantation procedure (David I) between 2004 and 2009. All patients had anatomically normally shaped tricuspid AVs free from any sort of leaflet alteration. The diameter of the sinotubular junction determined the diameter of the graft, with an additional oversizing of 1–2 mm. Straight Dacron grafts, sized 26, 28 and 30, were used.

One patient died of gastric cancer 1 year after the procedure and three patients were lost to follow-up. Seventeen patients were available for study. For every patient previously submitted to the David procedure, an adequate match for gender, age, body surface area (BSA) and LVEF% was found...
within the group of patients who are daily referred to our echocardiography clinic for a medical check-up. Patients in the two groups (David and Control), for this reason, belonged to the same referral area. A group of 18 subjects was identified for matching and comparison. The two groups were studied at baseline and after treadmill exercise according to Bruce’s protocol with the targets of 75% of predicted maximal heart rate or appearance of symptoms [7].

Measurements of left ventricular (LV) dimensions were made from 2D echocardiographic images in the parasternal long-axis view and M mode. LV volumes and ejection fraction (EF%) were calculated by modification of Simpson’s method with two apical views. AV regurgitation was graded on the basis of the regurgitant jet height/left ventricular outflow tract (LVOT) height ratio (mild (1+): <25%, moderate (2+): 25–46%, moderately severe (3+): 47–64% and severe (4+): ≥65%).

The LVOT area was calculated from the diameter of the outflow tract (area = diameter² × 0.78), assuming circulatory geometry. The velocity of the LVOT was obtained by pulsed-wave Doppler from the apical long-axis view, and the maximal instantaneous (AV) gradient was calculated from the peak aortic Doppler velocity by the modified Bernoulli equation (pressure gradient = 4×velocity²). With online software, mean AV pressure gradient and time velocity integral (TVI) of the AV and LVOT flow velocities were measured. Three to five cardiac cycles were measured and the values were averaged. AV area (AVA) was calculated using the continuity equation:

\[
AVA = \frac{\text{LVOT area} \times \text{LVOT TVI}}{\text{AV TVI}}
\]

LV mass (LVM) was calculated as described by Devereux et al. [8]. All patients had signed a written consent to the collection and eventual analysis of their personal medical data.

STATISTICAL ANALYSIS

Data were expressed as means ± standard deviation. Comparison between the groups (David and Control) was performed using the Student’s t-test for independent samples after having tested the normal distribution of the different variables. Normality of continuous variables was tested by means of the Wilk–Shapiro test. AVAs in the David group at rest and at maximal stress were compared using the Student’s t-test. Multiple linear regression was performed to identify the correlation between rest AVA (dependent variable) and group characteristics. SPSS 14.0 was used to perform the statistical analysis.

RESULTS

All continuous variables investigated were normally distributed. There were no significant differences in terms of age, height, weight, BSA, LVM, LVEF and tele-diastolic volume between the David and control group (Table 1). AV regurgitation in the David group was absent in five (29.4%), grade I in nine (52.9%) and grade II in three (17.6%) patients. At rest echocardiography, patients in the David group had a significantly lower-indexed AVA (IAVA) (David 1.1 ± 0.2 vs. Control 1.5 ± 0.2 cm²/m², \(P < 0.0001\)), with comparable transvalvular gradients (TVG) (Table 2). At maximal physical stress, although the IAVA in the David group was significantly increased from the rest values (rest AVA 1.1 ± 0.2 vs. peak stress AVA 1.4 ± 0.3; \(P = 0.001\)), the AVA difference between the groups persisted maintaining similar transvalvular peak and mean gradients (Table 2). Mean AV regurgitation in the David group remained unchanged during stress. Because AVA was the only echocardiographic variable differentiating the David from the control group, we tried to identify the correlation between rest AVA (dependent variable) and characteristics within the entire study cohort. At linear regression

<table>
<thead>
<tr>
<th>Table 1: Baseline characteristics in the two groups: David and Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>BSA (m²)</td>
</tr>
<tr>
<td>LVM (g)</td>
</tr>
<tr>
<td>LVEF %</td>
</tr>
<tr>
<td>B: Baseline; P: peak stress; AVA: aortic valve area. Notice that at maximal physical stress, the IAVA in the David group is significantly increased from the rest values (*P = 0.001).</td>
</tr>
</tbody>
</table>

| Table 2: Baseline and peak stress echocardiography data |
| B_Aortic max velocity (cm/s) | Control | 134.1 | 24.1 | 0.4 |
| B_Aortic mean velocity (cm/s) | Control | 95.1 | 18.5 | 0.9 |
| B_Aortic Mx grad (mmHg) | Control | 94.5 | 24.1 | 0.3 |
| B_Aortic mean grad (mmHg) | Control | 73.2 | 2.6 | 0.7 |
| B_AVA indexed (cm²/m²) | Control | 4.1 | 1.6 | 0.000 |
| P_Aortic maximum velocity (cm/s) | Control | 28.8 | 0.4 | 0.000 |
| P_Aortic mean velocity (cm/s) | Control | 168.7 | 33.2 | 0.2 |
| P_Aortic Mx grad (mmHg) | Control | 116.2 | 23.7 | 0.5 |
| P_Aortic mean grad (mmHg) | Control | 122.1 | 28.4 | 0.2 |
| P_AVA indexed (cm²/m²) | Control | 3.2 | 0.5 | 0.002 |

B: Baseline; P: peak stress; AVA: aortic valve area. Notice that at maximal physical stress, the IAVA in the David group is significantly increased from the rest values (*P = 0.001).
The absence of sinuses in our study group did not seem to have any influence on the parameters studied. It is interesting to observe an apparently normal function of the reimplanted AV in a straight tube as described originally by David, before the technical modifications (Valsalva graft, David IV and V) brought by the physiologic observations of recent years. In our study, fixation of the annulus and of the commissural posts inside a rigid tube does not alter the physiology of the valve. After all, it may very well be proved that, at long-term follow-up, the reimplanted valve works well even in the absence of the sinuses of Valsalva.

**LIMITATIONS**

The present study includes a limited cohort of patients. Although our statistical findings are significant and are supported by our clinical hypothesis, the effects of the David procedure on the dynamic performance of the AV should be investigated in larger samples. Furthermore, the cohort in analysis was operated upon during a relatively extended time span (~5 years) and the mean age of the group seems to be relatively high for patients submitted to a David operation. In reality, we submit to this operation only those patients who have an anatomically perfect AV (free from any sign of thickening or initial calcification) and this is reflected in the limited cohort size. Moreover, patients’ mean age refers to the value at the time of follow-up (for matching reasons we could not consider age at the time of surgery) and as a result is higher than expected. In any case, we do not have a specific age cut-off for the David operation, as long as the AV has a preserved anatomy. Finally, an analysis of the effects of intraoperative variables and follow-up duration on the haemodynamic performance of the AV was not performed and was beyond the aim of our analysis. In fact, the aim of the study was to determine whether the David procedure could, per se, have an impact on the AV performance at rest and under physical stress.

**Conflict of interest:** none declared.

**REFERENCES**

Aortic valve haemodynamics after aortic valve-sparing operations

Tirone E. David*

Division of Cardiovascular Surgery of Peter Munk Cardiac Centre, Toronto General Hospital and University of Toronto, Toronto, Ontario, Canada

* Corresponding author. Division of Cardiovascular Surgery of Peter Munk Cardiac Centre, Toronto General Hospital and University of Toronto, 200 Elizabeth St., 4N457 Toronto, Ontario MSG 2C4, Canada. Tel: +1-416-3405062; fax: +1-416-3404020; e-mail: tirone.david@uhn.ca (T.E. David).

Keywords: Aortic root surgery • Aortic valve sparing • Aortic valve haemodynamics

Basically, there are two basic types of aortic valve-sparing operations: remodelling of the aortic root and reimplantation of the aortic valve [1]. After more than 2 decades of experience with these operations, we have concluded that they are not competitive procedures, but provide excellent long-term results when correctly matched to the aortic root pathology [2, 3]. Remodelling of the aortic root is physiologically superior to reimplantation of the aortic valve [4], but it does not address the problem of annular dilatation that often occurs in young patients with inherited aortic root aneurysms. As the dilatation of the aortic annulus can appear after the remodelling procedure, we believe that young patients are better served with reimplantation of the aortic valve. Remodelling of the aortic root is a good alternative to reimplantation of the aortic valve in older patients with normal aortic annulus and it is easier to perform.

Regardless of the type of aortic valve sparing, restoration of normal aortic cusps geometry is the most important technical aspect of these operations. A key element for long-term success is the level and area of cusps coaptation. At the end of the procedure, the coaptation of the cusps must be inside the aortic root and a few millimetres above the level of the nadir of the aortic annulus, and the cusps coaptation length must be at least 4 mm.

Remodelling of the aortic root has practically no adverse effect on systolic performance of the aortic valve because it does not change the diameter of the aortic annulus and has minimal effect on the movements of the aortic annulus during the cardiac cycle. In addition, the velocity of opening and closure of the cusps is only slightly increased [4]. Reimplantation of the aortic valve into a Dacron graft (straight tube or the Valsalva Graft by Vascutek Ltd, Renfrewshire, Scotland) alters every component of the aortic valve: the annulus, the cusps, the sinotubular junction and the aortic sinuses. The aortic annulus becomes rigid once sutured inside the Dacron graft. The degree of narrowing of the annulus will vary with the size of the graft used and the technique used for fixation of the annulus. The sinotubular junction is reduced and the aortic sinuses completely abolished when a straight tubular Dacron graft is used. The velocity of opening and closure of the aortic cusps is greatly increased in this operation [4], but it can be decreased by creating neo-aortic sinuses [5] or by using the Valsalva Graft [6].

Fixation of the aortic annulus and reduction of its diameter will invariably increase the impedance of blood flow to some degree that is not seen after remodelling of the aortic root. Actually, there is a case report of aortic stenosis after the reimplantation procedure because of purse stringing of the aortic annulus during its fixation in the tubular Dacron graft [7]. This is caused by a technical error that can be prevented by using grafts of adequate size and carefully tying the sub-annular sutures [2, 3].

In this issue of this journal, D’Ancona et al. [8] from Palermo, Italy, published a study that examined the haemodynamics of the aortic valve after the reimplantation technique in 17 patients and compared it with that of 18 matched controls. Aortic valve function was assessed by echocardiography at rest and during maximal exercise. Area of the left ventricular outflow tract and flow velocities were measured and the derivatives were calculated. Aortic valve area index at rest was $1.1 \pm 0.2 \text{ cm}^2/\text{m}^2$ in the reimplantation group and $1.5 \pm 0.2 \text{ cm}^2/\text{m}^2$ in the control group ($P = 0.0001$), and during maximal exercise it increased significantly to $1.4 \pm 0.2$ in the reimplantation group and to $1.7 \pm 0.2$ in the control group. There were no differences between the groups in peak and mean transvalvular gradients at rest and during exercise. Most patients in the reimplantation group had mild aortic