Aortic cusp sizers to establish the functional classification of aortic insufficiency: algorithm and midterm outcome of operative repair

Mohammad Bashar Izzat*, Khaled Hamzeh, Fadi Mahmoud and Mohammad M. Bakour

 Damascus University Cardiac Surgery Hospital, Damascus, Syria

* Corresponding author. Damascus University Cardiac Surgery Hospital, PO Box 33831, Damascus, Syria. Tel: +963-113311432; e-mail: mbizzat@gmail.com (M.B. Izzat).

Received 5 February 2015; received in revised form 9 March 2015; accepted 13 March 2015

Abstract

OBJECTIVES: Wider adoption of aortic valve repair procedures is held up by the difficulty in recognizing the exact alterations that are responsible for aortic valve insufficiency. New aortic cusp sizers were developed to assist in aortic valve assessment in the operating theatre. Our objectives were to examine the efficacy of the aortic cusp sizers in establishing the functional classification of aortic valve insufficiency, and to report the midterm outcome in a group of patients who had undergone aortic valve repair guided by this device.

METHODS: A prospective clinical study was performed involving 33 consecutive patients (18 males, age range: 8–74 years) with severe aortic valve insufficiency (mean severity: 3.4 ± 0.5). The aortic cusp sizers were used as a template to identify existing cusp and root alterations. Consequently, the functional classification of aortic insufficiency was determined, and the appropriate techniques of aortic valve repair were implemented.

RESULTS: Aortic valve repair was successful in all patients. Procedures performed were 37 functional aortic annulus corrections, 9 cusp free-edge plications, 2 cusp repairs with autologous pericardium, 9 replacements of the ascending aorta and 2 reimplantation procedures. At a mean follow-up time of 18.3 ± 13.7 months, 1 patient underwent aortic valve replacement for recurrent aortic valve regurgitation, while aortic valve function remained stable in 32 patients, with aortic insufficiency ≤1+ in 27 (84.4%) patients and 1–1.5 in 5 (15.6%) patients, and no significant gradients across the aortic valves.

CONCLUSIONS: The aortic cusp sizers are valuable in establishing the functional classification of aortic insufficiency, and can guide implementation of aortic valve repair techniques successfully. This approach is analogous to that accredited for the success and wide adoption of mitral valve repair techniques, and is likely to assist in increasing the percentage of aortic valves that are repaired when compared with current practice.

Keywords: surgical equipment • aortic valve • surgery • repair • cardiac surgery

INTRODUCTION

The results of any valve repair surgery are related to the precision with which normal or nearly normal valve configuration can be achieved at the end of the procedure [1, 2]. While surgical techniques have been standardized to a certain extent, wider implementation of aortic valve repair techniques is still restricted by the intraoperative difficulty in recognizing the exact aortic cusp and root geometric alterations that are responsible for aortic valve insufficiency (AI). Recently, aortic cusp sizers (GEISTER® Medizintechnik GmbH, Foehrenstrasse 2, D-78532 Tuttinglen, Germany) were developed to assist in aortic valve assessment in the operating theatre [2], and preliminary clinical testing have demonstrated that these sizers can provide reliable insight into the mechanism of AI, and can guide selection and implementation of appropriate aortic valve repair techniques [2].

In this study, we describe the process of using the aortic cusp sizers to establish the functional classification of aortic root-valve abnormalities [3, 4], and report the mid-term outcomes in a group of patients who had undergone aortic valve repair based on this algorithm.

MATERIALS AND METHODS

Aortic cusp sizers

Development of the aortic cusp sizers was reported previously [2]. Briefly, each sizer represented an intact natural aortic leaflet that correlated with a proposed root diameter (range: 19–31 mm), and
this ‘matching’ root diameter (in millimetres) was marked on the handle that was added to the design (Fig. 1).

**Patient selection**

This is a single-centre observational study. Between January 2011 and December 2014, 33 consecutive patients (18 males, mean age: 44.5 ± 19.8 years) underwent aortic valve repair procedures for various aetiologies of aortic valve disease. Preoperative transthoracic echocardiography (TTE) confirmed that the aortic valve was tricuspid in every case, with the presence of isolated severe AI [5]. Transoesophageal echocardiographic (TOE) and computed tomographic scans of the aorta were performed in cases of dilatation of the aorta. Each patient signed an informed consent form, and the study protocol was approved by the local medical research committee.

**Echocardiographic aortic valve assessment**

Intraoperative TOE was used to establish the functional classification of AI as described by le Polain de Waroux et al. [6]. Briefly, three main mechanisms of AI were identified: dilatation of the aortic root (Type 1), excess cusp motion, including cusp prolapse and cusp fenestration (Type 2) and restrictive cusp motion (Type 3). Three subtypes of cusp prolapses were further identified: flail cusps, whole cusp prolapses and partial cusp prolapses.

**Intraoperative aortic valve assessment algorithm**

After median sternotomy, cardiopulmonary bypass was established and the heart was arrested with standard cardioplegic techniques. A transverse aortotomy was performed a few millimetres above the sinotubular junction, and the aortic cusp sizers were used to establish the functional classification of existing aortic root/valve abnormalities algorithmically as follows:

(i) First: each aortic valve cusp was examined individually. The cusp sizer that corresponded with the commissural height and cusp attachment line was selected, and was placed so that its deeper curve rested on the cusp attachment line (Fig. 2). A cusp was considered to have normal geometry (Type I) if its free edge and inner surface area matched that of the selected sizer, while it was considered to be either prolapsed (Type II) or restricted (Type III) if they were stretched out or retracted in comparison with the selected sizer, respectively. Cusp prolapses were further subcategorized into flail cusps (eversion of the cusp into the left ventricular outflow tract), partial cusp prolapses and whole cusp prolapses. Next, the integrity of individual aortic cusps were evaluated for perforation (Type Id).

(ii) Secondly: the ‘matching’ root diameter (as marked on the handle of the selected sizer) was noted for each cusp. If valve cusps were undiseased but unequal in size, the ‘matching’ root diameters indicated by the three cusps were averaged. On the other hand, if one or more of the cusps were either prolapsed or contracted, we averaged the ‘matching’ root diameters indicated by the undiseased cusps. This designated the root diameter that is required for complete coaptation of existing aortic cusps.

(iii) Thirdly: the functional aortic root was examined, and was considered to be dilated if its diameter was larger than the ‘matching’ root diameter at the level at the sinotubular junction (Type Ia), or aortoventricular junction (Type Ic), or both (Type Ib).

**Aortic valve repair techniques**

The established functional classification was used to guide the operative approach as follows: existing aortic cusp abnormalities were addressed first, and a cusp prolapse was corrected by free-edge plication at the raphe [7]. A cusp restriction was corrected by cusp augmentation with a pericardial patch [8, 9], and a cusp perforation was repaired with the autologous pericardium. The selected cusp sizer was used as a template in all cases.

Next, functional aortic root dilatations were corrected. An aortoventricular junction dilatation was corrected through subcommissural annuloplasty [10]. A mild-to-moderate sinotubular junction dilatation was corrected by passing a double pursestring of 4-0 Prolene suture around the junction, and tying it over a Hegar dilator that equalled the predetermined ‘matching’ root diameter. A severe type la dilatation (>45 mm) was managed by...
replacing the ascending aorta, while a David’s valve sparing procedure was opted for in case of a severe type Ib dilatation (>33 mm). In either case, a tube graft that equalled the ‘matching’ root diameter was selected.

Intraoperatively, TOE was systematically performed before and after cardiopulmonary bypass. An acceptable repair was defined as AI ≤1+ with a mean gradient of ≤15 mmHg. Any post-repair eccentric jet or AI >1+ was immediately addressed with additional repair manoeuvres; no patient left the operating theatre with AI >1+

Follow-up and data collection

All patients underwent TTE at discharge and at regular intervals during the follow-up course. Morbidity and mortality data were recorded prospectively according to standard guidelines [11] and analysed retrospectively. A clinical follow-up was 100% complete at a mean follow-up time of 18.3 ± 13.7 months.

RESULTS

Operative profile

The aetiology of AI was degenerative in 9 patients, annulo-aortic ectasia in 13 patients, congenital in 4 patients, acute aortic dissection in 6 patients and chronic aortic dissection in 1 patient. Operative findings and repair techniques are listed in Table 1. Valve repair was successful in all cases, and no procedure was converted to prosthetic valve replacement. Isolated aortic valve repair procedures were performed in 12 patients, while concomitant cardiac procedures were performed in 21 patients. These included 11 mitral valve repairs, 7 mitral valve replacements, 5 tricuspid valve repairs, 7 coronary artery bypass procedures, 3 resections of subaortic stenoses and two Maze-III procedures. The mean aortic cross-clamp time was 93 ± 31 min and the mean cardiopulmonary bypass time was 113 ± 41 min.

<table>
<thead>
<tr>
<th>Table 1: Intraoperative findings and aortic valve repair techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional classification of AI</td>
</tr>
<tr>
<td>Type I abnormalities</td>
</tr>
<tr>
<td>Type Ia</td>
</tr>
<tr>
<td>Type Ib</td>
</tr>
<tr>
<td>Type Ic</td>
</tr>
<tr>
<td>Type Id</td>
</tr>
<tr>
<td>Type II abnormalities</td>
</tr>
<tr>
<td>Type III abnormalities</td>
</tr>
<tr>
<td>Surgical repair techniques</td>
</tr>
<tr>
<td>Cusp prolapse repair</td>
</tr>
<tr>
<td>Repair of cusp defect with pericardium</td>
</tr>
<tr>
<td>Cusp augmentation with pericardium</td>
</tr>
<tr>
<td>Sinotubular junction remodelling</td>
</tr>
<tr>
<td>Subcommissural annuloplasty</td>
</tr>
<tr>
<td>Ascending aortic replacement</td>
</tr>
<tr>
<td>David’s aortic valve reimplantation</td>
</tr>
</tbody>
</table>

AI: aortic valve insufficiency.

Correlation between TOE and the intraoperative aortic valve assessment algorithm

The gross functional classification based on the use of the cusp sizers compared well with TOE in most cases. There was an excellent agreement in the identification of aortic root abnormalities (Type 1) and restrictive cusp motion (Type 3). TOE, however, was less accurate in the identification of Type 2 abnormalities (there were two false-positives and one false-negative) and in subcategorizing the different subtypes of cusp prolapses (TOE was more prone to overstate the degree of prolapse).

Clinical outcomes

There were no in-hospital or post-discharge deaths during the follow-up. One patient suffered from early recurrence of AI due to an overlooked inclusion of a large segment of myocardium into the base of the right coronary sinus (sinking sinus) [12]. Aortic valve replacement was performed in this case. Aortic valve function remained stable in all other patients, and the last echocardiography in non-reoperated patients showed AI <1+ in 27 (84.4%) patients, AI 1–1.5 in 5 (15.6%) patients and no patient with AI ≥2. There were no significant gradients across the aortic valves (14 ± 2 mmHg) except for a single patient with a mean transvalvular gradient of 32 mmHg 48 months after undergoing resection of the subaortic membrane in combination with subcommissural aortic annuloplasty.

Twenty-four (75%) patients were in New York Heart Association (NYHA) functional class I and 8 (25%) patients were in functional class II. Nine patients were receiving oral anticoagulants due to atrial fibrillation (2 patients) or concomitant replacement of other heart valves (7 patients). No episodes of haemorrhage or aortic endocarditis were observed.

DISCUSSION

In a recent editorial, Boodhwani and El Khoury [13] drew attention to the significant resemblance between the journey of aortic valve repair and that of mitral valve repair. Much like the time-honoured Carpentier classification of mitral valve disease, the emergence of the functional classification system of AI [3, 4] has been a critical landmark, and has provided a shared terminology for communication among cardiologists and surgeons. Similarly, surgical techniques of aortic valve repair have evolved from preserving the normally functioning valve leaflets in the context of annular pathology, to the more complex variety of leaflet repair and root remodelling techniques.

The third crucial element in the journey of mitral valve repair has been the development of mitral valve leaflet/annular sizers. These tools have made the application of mitral valve repair a more predictable endevour, and have become an essential objective/anatomical reference that facilitates patient-specific operative planning. Until recently, however, no matching instruments were at hand to facilitate aortic valve repair, and this has arguably been responsible for the slow adoption of aortic valve repair techniques by the worldwide community of surgeons. By incorporating the important lessons from the journey of mitral valve repair, it was evident that the rational approach to advance aortic valve repair techniques was to develop an objective tool for clarifying...
the mechanism of valve malfunction in accordance with the functional classification system of AI [3, 4].

A number of devices with diverse designs were recently developed to serve this purpose through measuring intercommissural distances [14], cusp heights [15] or aortic cusp dimensions [16], and collective evidence indicates that such devices are likely to lead to higher reproducibility of aortic valve repair methods [15, 17, 18]. Key advantages of our aortic cusp sizers are their ability to examine all dimensions of the aortic cusp (commissural height, cusp attachment line, free-edge length and cusp surface area), and to verify the presence of functional aortic root dilatation. As a result, the functional classification of AI can be established algorithmically, and the appropriate aortic valve repair technique can be selected [2]. An equally important feature, aortic cusp sizers can determine the ‘matching’ root diameter that is required for complete coaptation of existing aortic cusps, hence supplanting the previous complex sizing and calculation formulas that were based on various detailed measurements of cusp geometry [2, 19–23]. One application of this feature is in cases of ascending aortic aneurysm/dissection, where selecting the appropriate ascending aortic graft can be challenging due to the presence of sinotubular junction dilatation where selecting the appropriate ascending aortic graft can be challenging due to the presence of sinotubular junction dilatation [23]. We have found it extremely useful to select a tube graft that equalled the ‘matching’ root diameter, as indicated by the cusp sizers. Unlike the Schafers cusp height caliper [24], the aortic cusp sizers are only applicable in the assessment of tricuspid aortic valves, and we consider this to be their main limitation since the bicuspid anatomy can be encountered in ~30% of patients [4].

In this series, the cusp sizer that corresponded with the commissural height and cusp attachment line was used to examine cusp geometry. This is justified by the fact that the height of the commissure remains relatively constant, while other components of the functional aortic annulus may dilate in the setting of aortic root aneurysms [21].

In agreement with our prior preliminary experience [2], this series confirms that the aortic cusp sizers can provide reliable insight into the mechanism of valve malfunction, and can guide aortic valve repair techniques successfully. In addition, our data demonstrate that the intraoperative aortic valve assessment algorithm is more accurate than TOE assessment in the detailed anatomical evaluation of aortic root/valve abnormalities.

This approach was analogous to that attributed to the success and wide adoption of mitral valve repair techniques. We believe that the simplicity and reproducibility of this methodology is likely to assist in its dissemination, and may and further increase the percentage of aortic valves that are repaired when compared with current practice.

ACKNOWLEDGMENTS

There was no industry funding for this study. The authors had full control of the design of the study, methods used, outcome measurement, analysis of data and production of the written report.

Conflict of interest: M.B. Izzat discloses that he has a financial relationship with Geister Medizintechnik GmbH.

REFERENCES