Imaging techniques in aortic valve and root surgery

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PART I

Preoperative evaluation of patients with aortic regurgitation and/or aortopathy

Selection of candidates to valve-sparing aortic root reconstruction

Chapter 5:

Aortic valve and aortic root features in CT angiography in patients considered for aortic valve repair

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Abstract

Background: The underlying mechanism of aortic regurgitation, aortic valve and root characteristics have been associated with the durability of surgical repair. We investigated whether multidetector CT (MDCT) identifies the characteristics of the aortic valve and root that may be associated with the ability to perform successful surgical repair.

Methods: Sixty-one patients with aortic regurgitation and/or aortic root pathology who were evaluated for aortic valve or root repair and underwent clinically indicated gated or non-gated MDCT of the aortic valve and aortic root were included in the present analysis. Patients with endocarditis were excluded. MDCT data of aortic valve anatomy and calcification and thoracic aorta dimensions were analyzed.

Results: The aortic valve and root was successfully repaired in 36 patients (55±13 years; 61% male; median EuroSCORE II, 3.8%) whereas in 25 patients (56±15 years; 52% male; median EuroSCORE II, 2.5%) repair was not attempted (n=20) or valve repair was converted to aortic valve replacement during surgery (n=5). In patients in whom repair was considered not possible or failed, there was a higher percentage of bicuspid aortic valves (48% vs. 17%; p=0.019), more severe commissural calcification, and more severe annular calcification.

Conclusion: The degree of commissural and annular calcification of the aortic valve determined by MDCT is inversely related to the ability to perform surgical valve repair instead of replacement. Similarly, bicuspid valve anatomy predicts failure to perform repair.

Introduction

Valve-sparing aortic root replacement techniques are successfully performed in selected patients with aortic regurgitation (AR) and/or aortic root pathology.[1-4] The underlying mechanism of the AR and several morphological characteristics of the aortic valve and root have been associated with durable aortic valve repair.[5] Based on direct surgical inspection, a classification of AR mechanisms has been developed to guide the decision and feasibility of surgical aortic valve repair.[6] In AR type 1 (functional aortic annulus dilation) and AR type 2 (cusp prolapse), different aortic root and valve repair techniques may be applied unless the valve is heavily calcified. In contrast, in AR type 3 (cusp restriction), repair techniques are not recommended as the risk of failed repair and recurrent significant AR is high.[6] In addition, wide preoperative aortoventricular junction (AVJ) is associated with recurrence of AR after aortic valve repair.[7]

Two-dimensional transesophageal echocardiography (TEE) has been applied: (1) to identify the underlying mechanism of AR, (2) to characterize the anatomy and morphology of the aortic valve, (3) to assess geometry of the aortic root, and (4) to predict surgical reparability.[5] However, 2-dimensional TEE underestimates the diameters of the functional aortic annulus as compared with multidetector CT (MDCT).[8,9] MDCT provides high-spatial resolution data of the aortic valve and root characteristics and permits qualitative (morphology of aortic valve and root, extent of annulus, cusps and commissural calcification) and quantitative (dimensions) evaluation of the aortic valve and root that may be relevant for decision making.[10] The aim of the present study was to investigate whether MDCT provides preoperative insight into characteristics of the aortic valve and root that may be associated with feasible and successful aortic valve repair.

Methods

Patients

The institutional ethical committee approved this retrospective evaluation of clinically acquired data and waived the need for individual written patient consent. A total of 168 patients with AR and/or aortic root pathology were evaluated for surgical valve-sparing aortic root repair at the Leiden University Medical Center between 2003 and 2013. Patients with available preoperative MDCT data of the aortic valve and root were considered eligible for the present study. Patients with endocarditis were excluded. The study population consisted of 61 patients with AR and/or aortic root pathology. MDCT data of aortic valve anatomy and calcification and aortic root dimensions were analyzed and compared between patients who underwent successful valve-sparing aortic root repair (defined as postoperative AR $<$grade 2) and patients in whom repair was not successful or not feasible and who eventually underwent aortic root replacement using the Freestyle stentless bioprosthesis (Medtronic; Minneapolis, MN). Clinical and surgical data were collected in the departmental cardiology information system (EPD-Vision; Leiden University Medical Center, Leiden, the Netherlands) and retrospectively analyzed.

Multi-detector row computed tomography

MDCT studies were performed to evaluate the presence and extent of aortic root pathology within the Leiden University Medical Center in 40 patients with a 320-slice, 64-slice or 16-slice MDCT scanner (Aquilion; Toshiba Medical Systems, Tokyo, Japan). In the remaining 21 patients, the MDCT studies were performed at the referral hospitals. MDCT angiography data acquisition extended from above the aortic arch to the diaphragm, including the entire thoracic aorta. MDCT data were acquired during breathhold in deep inspiration, with tube potential of 100 or 120 kV and tube current adapted to body habitus, with intravenous contrast enhancement and no electrocardiographic triggering in 77% of patients. In 14 (23%) patients, the scans were electrocardiographically triggered at 45% or 75% of the R-R interval. Data were reconstructed with a slice thickness of 0.5 to 5 mm. All the MDCT datasets were loaded for off-line analysis to a dedicated remote workstation (Vitrea FX 1.0; Vital Images, Minnetonka, MN). MDCT angiography was not performed in patients with chronic kidney disease stage 4 or 5. Chronic kidney disease stage 3 (estimated glomerular filtration rate: 30-59 ml/min) was present in 8 patients. These patients were hydrated orally or intravenously before and after MDCT to prevent contrast-induced nephropathy.

Data analysis was performed by 2 experienced observers blinded to the reparability of the valve. Anatomy of the aortic valve (tricuspid or bicuspid), the degree of calcification of aortic valve, and AVJ[10,11] and the diameter of thoracic aorta at 10 different levels were evaluated.[12,13] Three orthogonal multiplanar reformation (MPR) planes were oriented to obtain the cross sectional plane parallel to the AVJ, just below the hinge points of the coronary cusps.[11]

By orienting the reconstructed single-oblique sagittal and coronal views across the aortic annulus, the true short-axis of the AVJ was displayed on the reconstructed double-oblique transverse view.[11] On this view, the anatomy of aortic valve (tricuspid or bicuspid) was identified, and the grade of commissural calcification was qualitatively assessed based on a scale from 0 to 3 (0= no calcification, 1= small calcium spots <5mm, 2= several calcium lesions >5mm and 3= heavy calcification of all cusps; Figure 1).[10,11] In addition, annular calcification was also visually assessed on a scale from 0 to 3 (0= no calcification, 1= 1 or multiple spots <5mm or one spot >5mm, 2= 2-3 spots >5mm and 3= >3 spots of >5mm diameter; Figure 1).[10]

From the double-oblique view the centerline was determined and on the orthogonal coronal and the single-oblique sagittal views, the coronal, and sagittal AVJ diameters were measured[11] (Figure 2) and the average diameter was calculated.

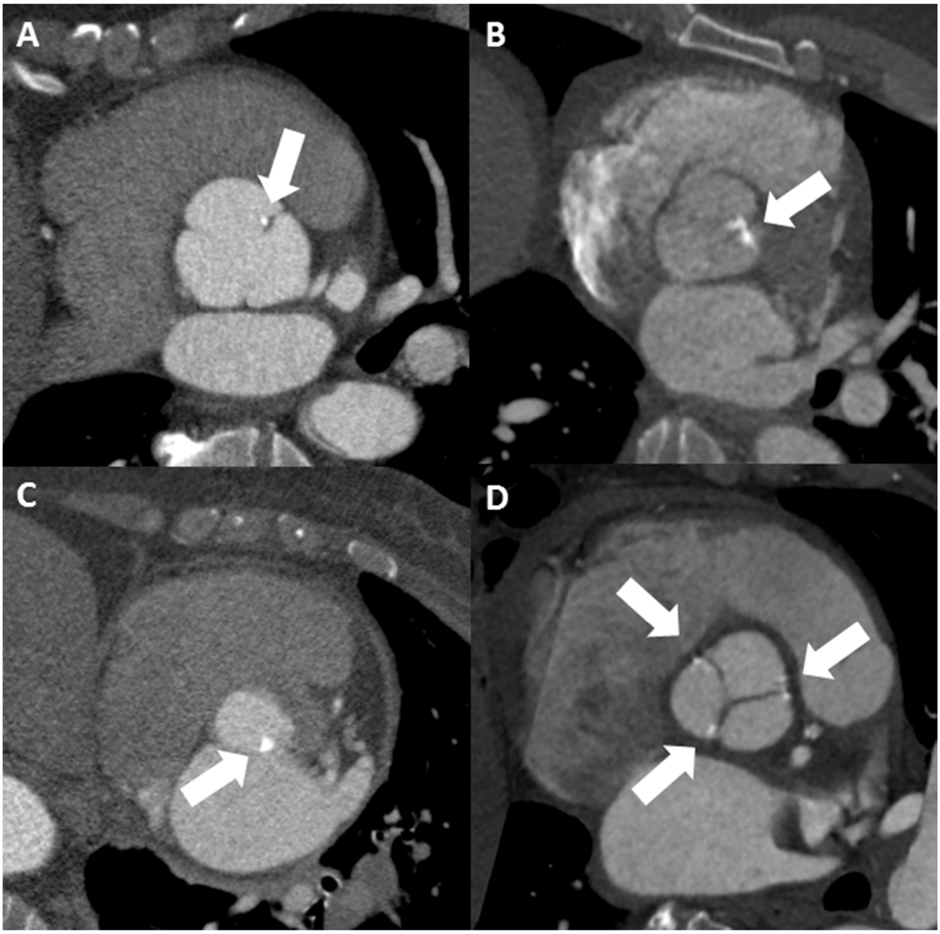

Figure 1. Classification of commissural and annular aortic valve calcification.
Commissural calcification was classified as grade 0 when there was no calcification, grade 1 when there were small calcium spots <5mm (A) or grade 2 when there were several calcium lesions >5mm (B). Annular calcification was considered grade 0 when there was no calcification, grade 1 when there were one or multiple spots <5mm or one spot >5mm (C) or grade 2 when there were 2-3 spots >5mm (D). Scans were acquired at 45 or 75% of R-R interval on 320-slice MDCT-scanner with tube potential of 100 or 120 kV and tube current adapted to body habitus.

The AVJ shape was evaluated by calculating the eccentricity index =1-(sagittal/coronal diameter); when the result of the equation was ≥0.1 the aortic annulus was considered ellipsoid.[14] Next, the diameter of the sinus of Valsalva (SOV) and sinotubular junction (STJ) at the single-oblique sagittal view, orthogonal to the double-oblique transverse view, were measured.[13]

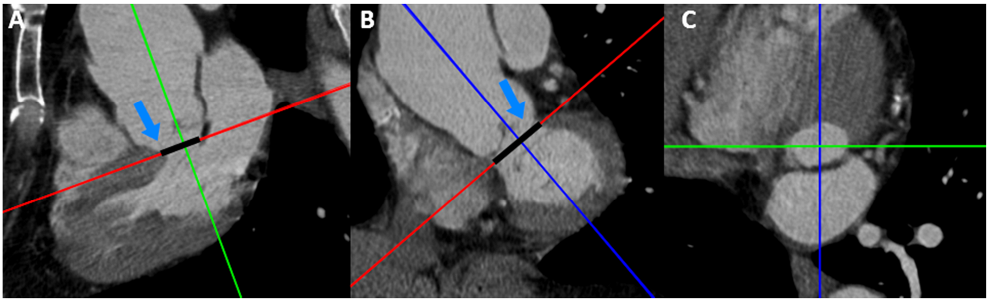

Figure 2. Measurement of aortoventricular junction on MDCT.

The 3 orthogonal multiplanar reformation planes (green, red and blue lines) were oriented on the single oblique sagittal (A) and coronal view (B) to visualize on the reconstructed double oblique transverse view (C) the true cross sectional plane of aortoventricular junction, just below the hinge points of the coronary cusps. The sagittal and coronal aortoventricular junction diameters, pointed by the blue arrows, were measured at the corresponding view (A and B respectively). In this example, the scan was acquired not electrocardiographically triggered on 16-slice MDCT-scanner with tube potential of 100 kV and tube current adapted to body habitus.

The diameters of the different levels of the thoracic aorta (at the level of the tubular ascending aorta, proximal and distal to the innominate trunk, proximal and distal to the left subclavian artery, proximal descending aorta and at the level of the diaphragm) were measured using the standard 3 MPR planes; the single-oblique and the coronal view were adjusted at each level to visualize the true cross-sectional view of each level at the double-oblique transverse view (Figure 3). Then, the aortic diameter at each level was measured at the single-oblique sagittal view.[12,13]

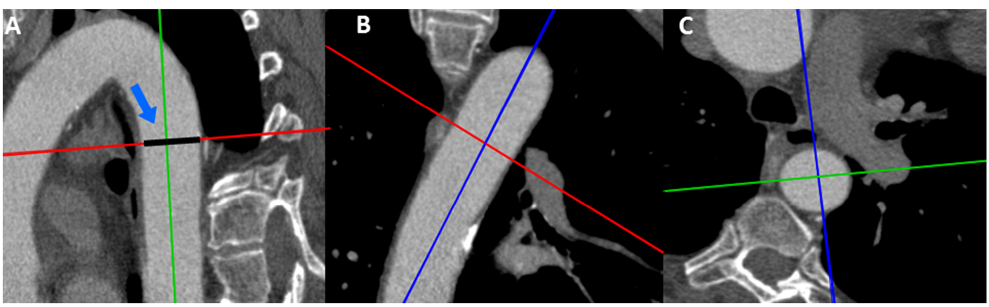

Figure 3. Measurement of thoracic aorta at the level of descending aorta on MDCT.

By using the standard orthogonal 3 multiplanar reconstruction planes (green, red and blue lines); the single oblique sagittal view (A) and the coronal view (B) were adjusted at descending aorta level to visualize the true cross sectional view at the double oblique transverse view (C). Then, the aortic diameter of descending aorta was measured (blue arrow) at the single oblique sagittal view (A). In this example, the scan was acquired not electrocardiographically triggered on 16-slice MDCT-scanner with tube potential of 100 kV and tube current adapted to body habitus.

Surgical repair

After median sternotomy, cardiopulmonary bypass was set through cannulation of the proximal part of the aortic arch or through femoral or preferably subclavian arterial route in patients with ascending aorta dissection or dilation. The aorta was transected at 2 cm above the ostium of the right coronary artery. The aortic root and valve were inspected by the surgeon and based on the AR mechanism, classified as type 1 (AR due to aortic root dilation), type 2 (AR due to cusp prolapse) or type 3 (AR due to cusp restriction).[6] Valve-sparing aortic root reconstruction was considered a feasible option in most type 1 and type 2 ARs unless heavy calcification of the aortic valve. If feasible, a vascular graft was implanted using either the reimplantation technique (modified David procedure) or the remodeling technique (Yacoub procedure) as previously described, with reimplantation of the coronary buttons.[15,16] In some cases, only the STJ was restored using a vascular graft.[17] Concomitant cusp repair techniques such as triangular resection, central cusp plication, resuspension, or shaving of the cusps were performed if needed.[18]

In patients with aortic valve and root considered non-reparable, aortic root replacement was performed using the Freestyle stentless bioprosthesis. The SOV and the aortic valve were excised. The bioprosthesis was then implanted with a 120° clockwise rotation with interrupted sutures, and the coronary buttons were reattached leaving 1 coronary ostium of the prosthesis unused.[19]

Statistical analysis

All data analyses were performed using the SPSS 20.0 (SPSS, Chicago, IL). Categorical variables were reported as frequencies and percentages. Continuous variables were displayed as mean ± standard deviation if normally distributed and as median and interquartile range if non-normally distributed. Differences between patients who underwent surgical valve-sparing aortic root reconstruction and patients who underwent aortic valve replacement were analyzed using the chi-square test, the unpaired Student *t*-test or Mann-Whitney U test as appropriate. All statistical tests were two-sided. A p-value <0.05 was considered statistically significant.

Results

The clinical characteristics of the patient population (mean age 56±14 years; 57% men) are listed in Table 1. Aortic valve and root repair was performed successfully in 36 patients (59%), with postoperative <grade 2 AR. The David reimplantation technique was performed in 24 patients (67%). The Yacoub remodeling technique was performed in 2 patients (6%). In the remaining 10 patients (28%), restoration of the STJ was performed. Additional subcommissural annuloplasty (so called Cosgrove stitches) was executed in 3 patients to diminish the AVJ

dimension. Various cusp repair techniques were performed in 9 patients (25%). Furthermore, in 25 patients (41%) aortic valve repair techniques were considered not feasible or unsuccessful. In 5 of these 25 patients, repair of the aortic valve and root was initially attempted but the residual postoperative AR grade was >2 and were converted to aortic root replacement using the Freestyle stentless bioprosthesis. The clinical characteristics of both groups of patients (aortic valve or root repair group and nonreparable group) were similar (Table 1).

Table 1. Baseline characteristics.

	Nonreparable (n=25)	**Reparable (n=36)**	**p-value**
Age (years)	56.3±14.6	55.4±13.2	0.796
Male	13 (52%)	22 (61%)	0.657
Smoking	7 (28%)	6 (17%)	0.438
Diabetes	2 (8%)	1 (3%)	0.745
Hypertension	9 (36%)	15 (42%)	0.858
Dyslipidemia	5 (20%)	5 (14%)	0.661
NYHA functional class			0.665
I	13 (52%)	17 (47%)	
II	7 (28%)	14 (39%)	
III	3 (12%)	3 (8%)	
IV	2 (8%)	1 (3%)	
Creatinin clearance (ml/min)	108.4±44.3	96.6±33.5	0.238
Chronic Kidney Disease			0.195
Stage 1	16 (64%)	17 (47%)	
Stage 2	5 (20%)	15 (42%)	
Stage 3	4 (16%)	4 (11%)	
EuroSCORE II (%)	3.8 (1.6-6.2)	2.5 (1.8-4.3)	0.747
Setting of surgery			0.754
Emergency	6 (24%)	11 (31%)	
Urgent	5 (20%)	5 (14%)	
Elective	14 (56%)	20 (56%)	
Mitral valve surgery	1 (4%)	4 (11%)	0.602
Tricuspid valve surgery	0 (0%)	4 (11%)	0.231
CABG	5 (20%)	6 (17%)	1.000

Data are presented as number (percentage), as mean ± standard deviation or as median (interquartile range). CABG: Coronary Artery Bypass Grafting; EuroSCORE II: European System for Cardiac Operative Risk Evaluation II; NYHA: New York Heart Association.

MDCT characteristics associated with reparable aortic root and valve

Among the various MDCT variables evaluated, 3 characteristics were more frequently associated with nonreparability: bicuspid anatomy, severe commissural calcification and annular calcification. The prevalence of bicuspid aortic valve (BAV) was significantly higher in the nonreparable group compared with the aortic valve or root repair group (48% vs. 17%; p=0.019). The degree of calcification of the commissures and the aortic annulus is displayed in Figure 4. The valve commissures were more calcified in the nonreparable group than in the aortic valve or root repair group (grade 1, 14% vs. 14%; grade 2: 29% vs. 0%, respectively; p=0.003). The annulus calcification grade was also higher in the nonreparable group than in the aortic valve or root repair group (grade 1, 5% vs. 14%; grade 2, 14% vs. 0%, respectively; p=0.043).

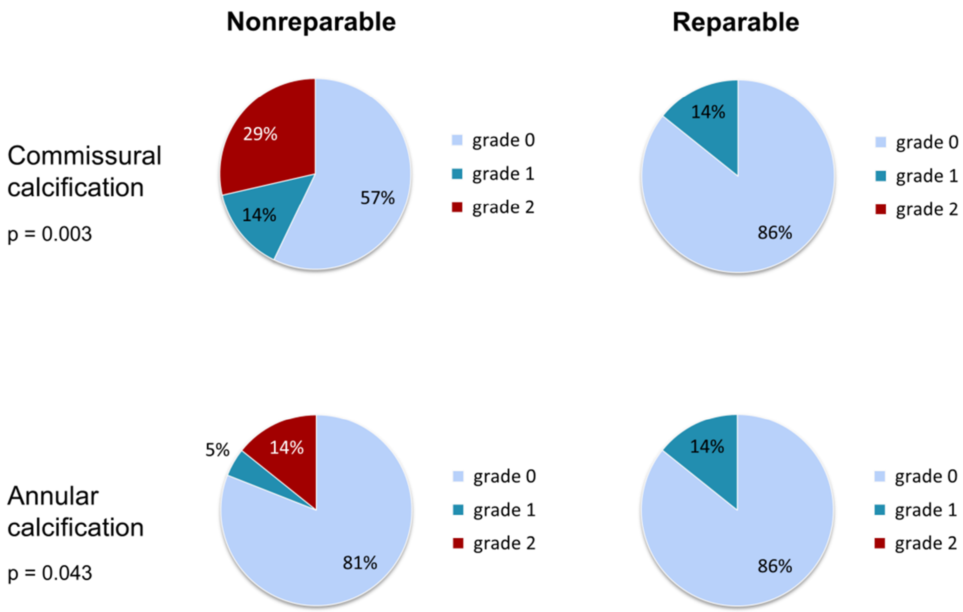

Figure 4. Grade of calcification.
Displayed in percentages per group for commissural calcification and annular calcification.

The eccentricity index of the AVJ was 0.24 in the nonreparable group, compared to 0.26 in the reparable group (p=0.696). The diameters of the aortic root and thoracic aorta were measured at 10 levels (Figure 5). Patients with a reparable valve tended to have a wider SOV compared with the patients in the nonreparable group (48.3±9.3 mm vs. 44.6±7.1 mm, respectively; p=0.103); however, this difference was not statistically significant. All other diameters were comparable between the 2 groups.

Discussion

The present analysis identified anatomic features of the aortic valve and root assessed on preoperative MDCT that may be associated with feasible and successful surgical repair of the aortic valve. Tricuspid anatomy and less commissural and annular calcification were associated with feasible and successful valve repair.

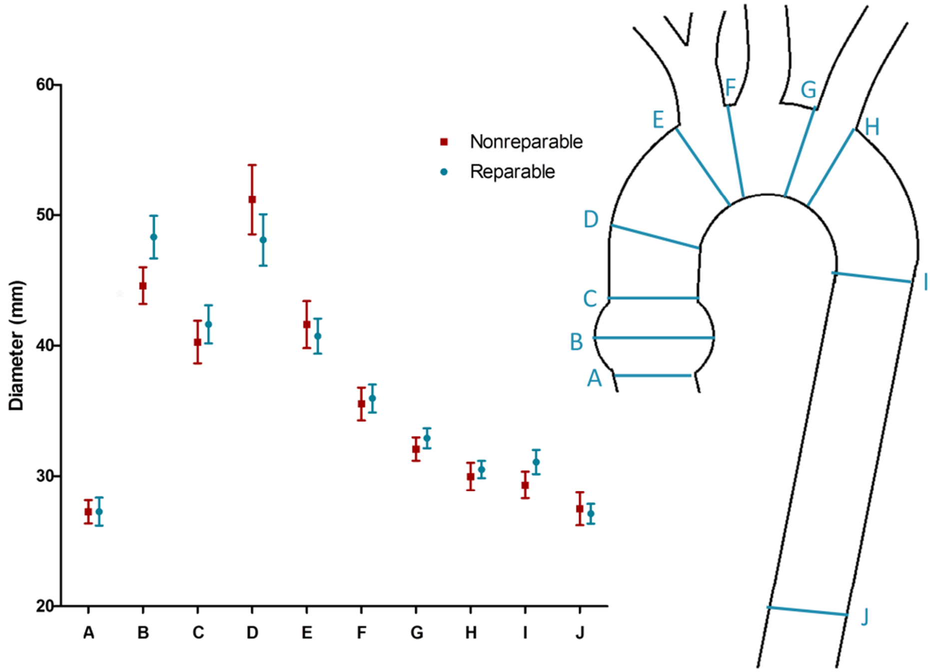

Figure 5. Diameters of the aortic root and thoracic aorta at 10 levels.
Data are displayed as mean and standard error of the mean (SEM).

Aortic valve morphology and geometry and aortic root dimensions are parameters associated with feasibility of surgical aortic valve repair. So far, most studies have evaluated these aspects with TEE.[5] However, MDCT may be frequently requested in AR associated with aortic root pathology. MDCT is highly accurate to differentiate between bicuspid and tricuspid anatomy (particularly in the presence of calcifications) and provides accurate measurements of aortic root and thoracic aorta.[9,20] Valve-sparing aortic root replacement techniques provide good outcomes in patients with BAV who are operated in highly experienced centers.[21,22] However, some valve characteristics have been associated with increased rates of reoperation (up to 20%).[23,24] For example, a commissural orientation of <160º (which indicates asymmetrical size cusps) has been suggested as a risk factor for reoperation in BAV.[1] In contrast, eccentric regurgitant jets and absence of cusp and commissural thickening or calcification have been associated with successful repair in patients with BAV.[25] In the present study, 67% of BAVs were considered nonreparable and importantly 36% had commissural calcification grade ≥2. Calcification extent is also an important characteristic associated with reparability in tricuspid anatomy of the aortic valve.[5] The present analysis demonstrated that higher grades of commissural and annular calcification (grade ≥2) were associated with higher probability of performing eventually an aortic valve replacement rather than aortic valve repair. Using 2-

dimensional TEE, le Polain de Waroux et al. showed that severe calcification of the aortic valve was associated with high recurrence rate of significant AR after surgical repair.[5] MDCT permits accurate assessment, quantification and location of aortic valve calcification and is considered the method of reference.[10]

In addition, several studies have shown less successful repair in patients with a wide annulus, that is, AVJ of >28 mm.[1,7,26] In the present series, the diameter of the AVJ was not different between patients in whom repair was feasible and patients who underwent valve replacement. However, there was a tendency towards a wider SOV in patients who underwent successful aortic valve and root repair. This may be attributed to different pathophysiologic types of aortic regurgitation.[27] Measurement of the aortic root and ascending aorta dimensions is accurately assessed with MDCT since this 3-dimensional imaging technique permits alignment of the MPR across the aortic root and ascending aorta, defining a centerline to avoid off-axis measurements. Therefore, MDCT, frequently requested before valve-sparing aortic root replacement techniques to assess concomitant aortic pathology, provides several important data (morphological and quantitative) that may help to identify the patients in whom AR repair may be successfully performed.

Clinical perspective

MDCT forms a part of the preoperative assessment of patients with AR associated with aortic root pathology. Dimensions of the aortic root and ascending aorta are accurately obtained with MDCT and are paramount to decide the surgical approach.[7,9] However, it is important to note that MDCT data can also provide useful information on the aortic valve anatomy and morphology that can indicate whether aortic valve repair may be successful or not. Furthermore, current advances on computational fluid dynamics have provided insightful data on the pathophysiology of aortic diseases.[28,29] These novel algorithms permit quantification of wall shear stress of the aorta and dynamic pressures of the aortic flow as well as qualitative evaluation of the streamlines that may refine the underling mechanism of AR and predict the feasibility and durability of repair.

However, there are subgroups of patients with contraindications for MDCT in whom these aspects may be analyzed with other imaging techniques. For example, in patients with concomitant stage 4 to 5 chronic kidney disease, MDCT may be contraindicated.[30] In this group of patients, magnetic resonance imaging may be a valuable 3-dimensional imaging technique to assess some of the aforementioned variables. However, calcification of the aortic valve may be difficult to assess with MRI. Currently, TEE is the most frequent technique to assess the grade and mechanism of AR. However, this technique is semi-invasive and does not provide information on the aortic arch at the level of the brachiocephalic and left common carotid arteries. Integration of information obtained with TEE and MDCT may accurately predict which patients may be suitable for aortic valve-sparing surgical techniques and which type of technique may be the most appropriate. This may result in adequate referral of suitable patients to high-volume centers performing durable aortic valve repair techniques. Additional studies evaluating the impact of a systematic assessment of the aortic valve or root with TEE and MDCT on the outcomes of surgical aortic valve repair techniques would establish the role of these imaging techniques in the clinical management of patients with aortic root pathology associated or not with AR.

Limitations

The present analysis is limited by its retrospective observational nature. Although the surgical repair technique performed by the surgeon was not influenced by the preoperative MDCT data, the relatively small number of patients precluded us to perform statistical analysis to investigate the independent determinants or predictors of successful aortic valve repair. Furthermore, transesophageal echocardiographic assessment to identify the patients in whom aortic valve repair may be feasible was not systematically available. Therefore, the incremental value of MDCT assessment combined with transesophageal echocardiographic evaluation to predict aortic valve reparability could not be investigated. Quantification of aortic valve and root calcification using the Agatston score was not possible because non-contrast enhanced MDCT data were not systematically available. MDCT was performed on a 320-, 64- or 16-slice scanner which may have induced heterogeneity in the MDCT data. MDCT data acquisition was not electrocardiographic triggered in the majority of patients which may have resulted in artifacts particularly in the aortic root and ascending aorta that may hamper the reproducibility of the measurements. However, in our series there were no patients excluded because of non-analyzable MDCT data. Moreover, MDCT data were not consistently acquired in diastole or systole which may introduce an important bias. In 21 patients, MDCT was performed at the referral hospital and information on MDCT data acquisition was not systematically available. Lastly, MDCT angiography is not the imaging technique of first choice in patients with severe chronic kidney disease (stage 4 or 5),[30] and therefore, the results of the present study may not be generalizable to this subgroup of patients.

Conclusion

Tricuspid valve anatomy and less commissural and annular calcification are significantly associated with feasible and successful aortic valve and root repair. The information provided by MDCT regarding valve morphology and calcification might be helpful in determining the surgical strategy in patients with aortic root pathology, associated or not with AR.

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