Comparison of two- and three-dimensional transthoracic echocardiography for measurement of aortic annulus diameter in children

Comparaison de l’échocardiographie 2D et 3D dans la mesure de l’anneau aortique chez l’enfant

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Received 11 April 2013; received in revised form 4 June 2013; accepted 11 June 2013
Available online 23 September 2013

KEYWORDS
Aortic valve; Three-dimensional echocardiography; Children; Aortic annulus; Two-dimensional echocardiography

Summary
Background. — Accurate evaluation of aortic root geometry is necessary in congenital aortic valve lesions in children, to guide surgical or angiographical intervention.
Aim. — To compare aortic annulus diameters measured by two- and three-dimensional transthoracic echocardiography (2D- and 3D-TTE), to determine the feasibility and reproducibility of 3D imaging and assess the dynamic changes during the cardiac cycle.
Methods. — Thirty children without heart disease were prospectively included. Two orthogonal aortic annulus diameters were measured offline using multiplanar reconstruction in diastole and in systole and were compared with the measurement of the aortic annulus diameter by 2D-TTE.
Results. — Mean age was 11 ± 3.6 years. Feasibility of 3D imaging was 100%. The coefficients of intra- and interobserver variability were 3.5% and 6%, respectively. The 2D mean diameter was significantly smaller than the 3D maximum diameter in systole (1.94 vs. 2.01 mm; p = 0.005).

Abbreviations: 2D, two-dimensional; 2D-TTE, two-dimensional transthoracic echocardiography; 3D, three-dimensional; 3D-TTE, three-dimensional transthoracic echocardiography; CI, confidence interval; Dmax, maximum diameter; Dmin, minimum diameter; SD, standard deviation.
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1875-2136/ — see front matter © 2013 Published by Elsevier Masson SAS.
http://dx.doi.org/10.1016/j.acvd.2013.06.049
Background

Aortic valvular stenosis is a relatively common congenital heart disease, involving about 6–7% of infants born with congenital heart disease [1]. Invasive treatment, by either surgical or percutaneous procedures, requires an accurate assessment of the aortic root geometry, especially of the aortic annulus diameter, to minimize the risk of complications, such as aortic regurgitation. Previous studies performed in adults with severe aortic stenosis suggested an underestimation of the aortic annulus diameter with two-dimensional (2D) echocardiography compared with tomography [2]. Only a few studies have addressed this subject in a paediatric population [3]. Real-time three-dimensional echocardiography (3D-TTE) is an emerging non-invasive technique, useful in the evaluation of cardiac chamber volumes and mass, and left ventricular wall motion and in the analysis of morphology and function of heart valves [4]. The aim of our study, therefore, was to investigate the value of 3D echocardiography by comparing 2D-TTE and 3D-TTE measurements of the aortic annulus diameter in children without any cardiac condition.

Methods

Population

Echocardiography data were collected prospectively. Only children with normal cardiac anatomy and function assessed by physical examination, electrocardiography and standard 2D echocardiography were included in the study; real-time 3D-TTE images were then acquired. Children with bicuspid aortic valve or any aortic root disease were not selected. Informed verbal consent was obtained from each patient and legal representatives after a full explanation of the procedure had been given. A written consent form was not required according to French law, given that the echocardiography evaluation was part of the regular management of the children and was required by their medical condition. The study protocol was approved by the National Commission for Data Processing and Freedoms (No. 1673449). No additional examination was performed for the sole purpose of the study. Thirty patients were included between December 2011 and April 2012 in the echocardiography laboratory of the
Paediatric Cardiology Unit, Children’s Hospital, Toulouse, France.

Echocardiography and data analysis

Real-time 2D and 3D-TTE were performed using a commercially available IE33 ultrasound system (Philips Medical Systems, Andover, MA, USA). X7-2, X5-1 or X3-1 matrix probes were used, depending on the age of patient. The X7-2 matrix array transducer is particularly well suited to 3D echocardiography in small children [5].

The examination was performed with the child in a decubitus position. Parameters of gain and compression were optimized. 2D-TTE images were acquired in parasternal long-axis view focused on the aortic annulus area. Aortic annulus diameter was measured in a single plane in end-diastole and mesosystole, between the insertion of the right coronary and non-coronary cusps, using a zoom mode based on international guidelines [6] (Fig. 1). Real-time 3D-TTE images were acquired in parasternal long-axis view using ‘real-time’ 3D mode The 3D loop was turned 90° to obtain a view of the aortic annulus from the left ventricle, to check that the 3D dataset encompassed the whole aortic annulus. The 3D dataset was stored in a DICOM format and transferred to a separate workstation for off-line data analysis. Off-line data analysis was performed using QLab 9 software (Philips Medical Systems, Andover, MA, USA).

Off-line image analysis

Parameters of gain and compression were optimized. Multiplanar reconstruction mode was used, with three independent orthogonal cutting planes. Two orthogonal planes were in the long axis of the left ventricle. The third plane was perpendicular to the two others and moved at the insertion of aortic cusps to obtain a short-axis 2D plane of the aortic annulus. Care was taken to place the plane exactly at the insertion of the leaflets, as recommended [6]. Horizontal and vertical diameters of the aortic annulus were measured in both end-diastole and mesosystole. When the orthogonal diameters were different, the largest diameter was called the maximum diameter (Dmax) and the smallest the minimum diameter (Dmin) (minor and major axes) (Fig. 2).

Reproducibility

Real-time 3D-TTE loop acquisitions were performed by a single confirmed operator. To assess interobserver variability, the 3D dataset was analysed off-line by a second independent operator with the same level of experience of QLab software. To evaluate intraobserver variability, the first operator did the measurements twice, on different days, blinded to the previous results. Variability was not estimated for the 2D measurements.

Statistical analysis

Baseline characteristics were summarized using means and standard deviations (SDs) for continuous variables, and numbers and percentages for categorical variables. First, Spearman’s correlation coefficients were estimated to assess the correlation between 2D and 3D measurements (3D horizontal diameter, 3D vertical diameter, 3D minimum diameter and 3D maximum diameter) with their 95% confidence intervals (CIs) in systole and diastole. A paired Student’s t test was used to compare the mean difference between the 2D and 3D measurements after the assumptions of normality of the dependent variable and homogeneity of variance were checked. Second, an eccentricity index was calculated, expressed as the difference between the maximum and minimum 3D diameters divided by the maximum diameter as a percentage (Dmax—Dmin/Dmax), to assess the aortic annular geometry in systole and diastole. Therefore, an eccentricity index of zero represents a perfect circle, whereas a progressively higher eccentricity index represents a more elliptical geometry. The Bland-Altman method was used to further investigate the differences between 2D and 3D measurements in systole and diastole [7]. Third, comparisons between systolic and diastolic 2D and 3D aortic annulus diameters were made using a paired Student’s t test, after the assumptions of normality of the dependent variable and homogeneity of variance were checked. The Bland-Altman method was used to further investigate the differences between systolic and diastolic measurements. Finally, interobserver and intraobserver variabilities were investigated by calculating an intraclass correlation coefficient and a variation coefficient. The latter was calculated as the absolute difference between two measurements divided by the average of the two measurements as a percentage. The variation coefficient was calculated as the mean of the variation coefficient for the horizontal and vertical diameters in diastole and in systole. Statistical difference was considered as significant when the p value was < 0.05. Statistical analysis was performed using Stata® 11.2 software (StataCorp LP, College Station, TX, USA).

Results

Population

Children were referred to the echocardiography laboratory for investigation of a cardiac murmur or before anticancerous chemotherapy. Mean age was 11 ± 3.6 years (range, 3.3–17.6 years); mean height was 142.6 ± 22.2 cm; mean weight was 37.8 ± 14.8 kg (range, 14.2–64.0 kg);
mean left ventricular shortening fraction was 35.4 ± 3.5%; and mean end-diastolic left ventricular diameter was 36.5 ± 7.1 mm/m².

Feasibility and reproducibility

Aortic annulus diameter measurement was feasible in 2D and 3D in all 30 patients (100%, 95% CI 95.4–100%). The coefficients of variation for intraobserver variability were 3.3% (95% CI 1.7–4.9%) and 5.4% (95% CI 2.3–8.5%) for the horizontal and vertical diameters, respectively. Interobserver variability was 6.8% (95% CI 3.4–10.1%) and 5.3% (95% CI 2.3–8.2%) for the horizontal and vertical diameters, respectively. The intraclass correlation coefficient was 0.91.

Comparison between 2D and 3D aortic annulus diameters in systole

The 2D and 3D aortic annulus diameter measurements in systole are reported in Table 1. Comparisons between aortic annulus diameter measurements in systole are summarized in Table 2, as well as Spearman’s correlation coefficients within 2D and 3D measurements. Correlations between the aortic annulus diameter in 2D and the maximum and minimum diameters in 3D were excellent ($r = 0.92, p < 0.0001$ and $r = 0.88, p < 0.0001$, respectively). The correlation coefficients between 2D and horizontal or vertical diameters were $r = 0.87 (p < 0.0001)$ and $r = 0.90 (p < 0.0001)$, respectively. However, the 2D aortic annulus diameter in systole was significantly higher than the minimum diameter obtained in 3D ($p = 0.02$) and significantly smaller ($p = 0.005$) than the maximum diameter obtained in 3D. The mean difference between the 2D diameter and the maximum 3D diameter was 1.1 ± 0.8 mm (95% CI 0.8–1.4 mm). The mean difference between the maximum and the minimum diameters of the aortic annulus was 1.3 ± 0.9 mm (95% CI 0.9–1.6 mm; $p < 0.001$). The mean eccentricity index in systole was 6.5 ± 4.1% (95% CI 4.9–8.1%). However, given that the maximum aortic annulus diameter was not always in the same axis, there was no significant difference between the mean vertical and horizontal diameters ($p = 0.2$). This fact is illustrated by the Bland-Altman analysis (Fig. 3A).

The Bland-Altman analysis revealed that although the mean difference between the two orthogonal diameters was weak (0.37 mm), the spectrum of difference data were relatively wide ranging, from −1.96 SD = −3.3 mm and +1.96 SD = +2.7 mm. Moreover, the difference between the two diameters was not related to the size of the annulus.

Comparison between 2D and 3D aortic annulus diameters in diastole

The 2D and 3D aortic annulus diameter measurements in diastole are reported in Table 1. Comparisons between aortic annulus diameters measurements in diastole are summarized in Table 3, as well as Spearman’s correlation coefficients within 2D and 3D measurements.
Table 1  Aortic annulus diameters measured by two- and three-dimensional transthoracic echocardiography.

<table>
<thead>
<tr>
<th>Aortic annulus diameter</th>
<th>Mean (cm)</th>
<th>95% CI</th>
<th>Minimum (cm)</th>
<th>Maximum (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systole</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2D</td>
<td>1.94</td>
<td>1.83–2.06</td>
<td>1.44</td>
<td>2.39</td>
</tr>
<tr>
<td>3D vertical</td>
<td>1.96</td>
<td>1.84–2.08</td>
<td>1.33</td>
<td>2.5</td>
</tr>
<tr>
<td>3D horizontal</td>
<td>1.93</td>
<td>1.80–2.05</td>
<td>1.39</td>
<td>2.39</td>
</tr>
<tr>
<td>3D minimum</td>
<td>1.88</td>
<td>1.76–2</td>
<td>1.33</td>
<td>2.39</td>
</tr>
<tr>
<td>3D maximum</td>
<td>2.01</td>
<td>1.89–2.12</td>
<td>1.39</td>
<td>2.5</td>
</tr>
<tr>
<td>3D mean</td>
<td>1.95</td>
<td>1.83–2.06</td>
<td>1.36</td>
<td>2.44</td>
</tr>
<tr>
<td><strong>Diastole</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2D</td>
<td>1.95</td>
<td>1.86–2.04</td>
<td>1.5</td>
<td>2.4</td>
</tr>
<tr>
<td>3D vertical</td>
<td>1.95</td>
<td>1.85–2.06</td>
<td>1.43</td>
<td>2.47</td>
</tr>
<tr>
<td>3D horizontal</td>
<td>1.99</td>
<td>1.88–2.1</td>
<td>1.46</td>
<td>2.62</td>
</tr>
<tr>
<td>3D minimum</td>
<td>1.93</td>
<td>1.82–2.03</td>
<td>1.43</td>
<td>2.47</td>
</tr>
<tr>
<td>3D maximum</td>
<td>2.01</td>
<td>1.90–2.12</td>
<td>1.47</td>
<td>2.62</td>
</tr>
<tr>
<td>3D mean</td>
<td>1.97</td>
<td>1.86–2.08</td>
<td>1.45</td>
<td>2.54</td>
</tr>
</tbody>
</table>

2D: two-dimensional; 3D: three-dimensional; CI: confidence interval.

Table 2  Comparison of two-dimensional (2D) and three-dimensional (3D) measurements in systole.

<table>
<thead>
<tr>
<th></th>
<th>2D systole</th>
<th>3D horizontal</th>
<th>3D vertical</th>
<th>3D minimum</th>
<th>3D maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D systole</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D horizontal</td>
<td>0.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.44</td>
<td>0.88&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.20</td>
<td>1</td>
</tr>
<tr>
<td>3D vertical</td>
<td>0.90&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.57</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.001</td>
<td>0.95&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3D minimum</td>
<td>0.88&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.02</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.001</td>
<td>0.95&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3D maximum</td>
<td>0.92&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.005</td>
<td>0.94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.0001</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3D mean</td>
<td>0.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.94</td>
<td>0.92&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.20</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Corr.: Spearman’s correlation coefficient.
<sup>a</sup> Indicates p value < 0.0001.

Correlations between the aortic annulus diameter in 2D and the maximum and minimum diameters in 3D were good (r = 0.81, p < 0.0001 and r = 0.80, p < 0.0001, respectively). The correlation coefficients between 2D and horizontal or vertical diameters were r = 0.82 (p < 0.0001) and r = 0.78 (p < 0.0001). The mean diameter in 2D-TTE and the minimum diameter in 3D-TTE were not significantly different (p = 0.44). The mean diameter in 2D-TTE tended to be smaller than the maximum diameter obtained in 3D-TTE, although the difference was not significant (p = 0.06). The maximum and the minimum diameters of the aortic annulus measured by real-time 3D-TTE were significantly different.

Table 3  Comparison of two-dimensional (2D) and three-dimensional (3D) measurements in diastole.

<table>
<thead>
<tr>
<th></th>
<th>2D diastole</th>
<th>3D horizontal</th>
<th>3D vertical</th>
<th>3D minimum</th>
<th>3D maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D diastole</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D horizontal</td>
<td>0.82&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.96</td>
<td>0.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.09</td>
<td>1</td>
</tr>
<tr>
<td>3D vertical</td>
<td>0.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.28</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.0001</td>
<td>0.98&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3D minimum</td>
<td>0.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.44</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.0001</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3D maximum</td>
<td>0.81&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.06</td>
<td>0.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.01</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3D mean</td>
<td>0.81&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.56</td>
<td>0.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.09</td>
<td>0.98&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Corr.: Spearman’s correlation coefficient.
<sup>a</sup> Indicates p value < 0.0001.
The mean difference between the two measurements was 0.8 ± 0.7 mm (95% CI 0.6–1.1 mm). The mean eccentricity index was 4 ± 3% (95% CI 3–5%). However, given that the maximum aortic annulus diameter was not always in the same axis, there was no significant difference between the mean vertical and horizontal diameters (p = 0.09). This fact is illustrated by the Bland-Altman analysis (Fig. 3B).

The Bland-Altman analysis revealed that although the mean difference between the two orthogonal diameters was weak (0.33 mm), the spectrum of difference data were relatively wide, ranging from −1.96 SD = −1.73 mm and +1.96 SD = +2.39 mm. Moreover, the difference between the two diameters was not related to the size of the annulus.

**Comparison between systolic and diastolic aortic annulus diameters measured by 2D- and 3D-TTE**

The systolic and diastolic aortic annulus diameter measurements are reported in Table 1. Comparisons between aortic annulus diameters measurements in systole and diastole are summarized in Fig. 4. The differences between diastolic and systolic mean aortic annulus diameters measured by 2D-TTE or 3D-TTE were not significant. Bland-Altman analysis revealed that differences between systolic and diastolic diameters extended from −1.96 SD = −2.39 mm to +1.96 SD = +1.19 mm for the horizontal diameter (Fig. 5A) and from −1.96 SD = −2.96 mm to +1.96 SD = +4.88 mm for the vertical diameter (Fig. 5B). Moreover, the difference between the systolic and diastolic diameters did not seem to be related to the size of the annulus.

**Discussion**

In this study, we demonstrated that real-time 3D echocardiography is a feasible method for assessing the aortic annulus diameter in children. Aortic annulus diameters measured in 2D and 3D were well correlated. The method appeared to be reproducible, with good intra- and interobserver agreement. Real-time 3D mode was preferred to 3D full volume scan, given that it is less time consuming and does not require multiple cardiac cycles for image acquisition. 3D full volume scan is always difficult to obtain without motion artefact in children. Our results support the findings of previous studies, confirming the value of 3D echocardiography in the assessment of the aortic root in children and adults. The usefulness of 3D echocardiography for classification of the bicuspid aortic valve has been underlined previously in children [8]. Goland et al. estimated the aortic valve area with good accuracy and reproducibility in patients with severe aortic stenosis, using 3D-guided and real-time 3D echocardiography [9]. A recent study in a population of adults with aortic stenosis showed that 3D transoesophageal echocardiography was an accurate method for evaluating aortic root geometry and should be considered as a non-invasive no radiation alternative to multidetector computed tomography [10]. Real-time 3D-TTE has also been reported to give accurate information about valvular dimensions and morphology in congenital bicuspid aortic valve, with an excellent correlation with surgical assessment [11]. These findings suggest that this technique can be used routinely in the assessment of the aortic valve in children.
Moreover, 3D echocardiography provides new information about the shape of the aortic annulus. In our study, the long-axis and short-axis annulus diameters were significantly different in both systole and diastole, even if the difference was weak (0.8 ± 0.7 mm in diastole and 1.3 ± 0.9 mm in systole). These results demonstrate that the shape of the aortic annulus is not perfectly round but tends to be oval. Moreover, the asymmetry of the annulus was not always in the same axis. Several multidetectors computed tomography studies in adults with acquired aortic stenosis have also shown that the aortic annulus is not round but oval [12,13]; but our study is the first, to our knowledge, to show the eccentricity of the aortic annulus in children. Therefore, the asymmetry of aortic valve annulus may not be related to aortic valve abnormalities but may also pre-exist in young healthy children.

Given the asymmetric geometry of the aortic annulus, 2D-TTE often underestimates the aortic annulus diameter [2]. We also observed in our study that the maximum diameter in 3D was significantly larger than the 2D diameter in systole. In diastole, maybe because of our small sample size, the difference did not reach significance. A 3D imaging technique, such as real-time 3D-TTE, provides a more accurate evaluation by integrating global comprehension of aortic root geometry with good image plane orientation and the possibility of doing measurements in multiple axes [14–16]. Using 3D echocardiography, the left ventricular outflow tract has also been described as elliptical in a cohort of healthy adults [17].

There were no significant differences between the mean aortic annulus diameter measured in diastole and in systole. However individual variations were high. Our findings are in agreement with a previous tomography study in a healthy population [18]. Because of the lack of research into this subject, it is a real challenge to provide an accurate explanation. We suggest that the complex anatomy of the aortic annulus, composed of a fibrous wall in continuity with the mitral valve and a muscular and membranous wall, may explain this important variability [15,16].

Our study has several limitations. First, our measures were not compared with a gold standard. However no examination has been validated as a gold standard for the assessment of the aortic annulus diameter. Tomography seems an interesting examination, given the high spatial resolution. In a previous study in adults, aortic annular dimensions were underestimated by 2D and 3D transesophageal echocardiography compared with tomography [13]. The role of cardiac magnetic resonance imaging is not well defined. A previous study compared the accuracy of annulus aortic measurements obtained from 3D echocardiography, tomography and cardiac magnetic resonance in vivo and in vitro [19]. The results showed that cardiac magnetic resonance was the most accurate method for the in vitro model. It would be interesting to compare aortic annulus diameters measured by these different techniques in children. In our study, however, this was not done for ethical reasons. Tomography requires X-rays and cardiac magnetic resonance imaging often requires general anaesthesia in young children. In our study, the children had normal aortic valves. It would be interesting to assess if our results could be extended to patients with bicuspid aortic valve and/or aortic valvular stenosis.

Balloon aortic valvuloplasty is considered as a good alternative to surgical valvotomy in severe congenital aortic stenosis [20,21]. The main risk of the procedure is the occurrence of aortic regurgitation. Previous studies suggested the need for an adequate ratio of balloon/aortic annulus diameter to limit the degree of aortic regurgitation [22]. Aortic regurgitation may occur with an oversized balloon, whereas residual stenosis may occur with an undersized balloon. An echocardiographical study has also described the usefulness of continuous 2D echocardiography guidance during the balloon aortic valvuloplasty procedure, to limit fluoroscopy time and the degree of aortic regurgitation [23]. Moreover, minimizing radiation doses in children is of great importance because of their higher tissue radiosensitivity [24]. A recent study compared, during balloon aortic valvuloplasty, the aortic annulus diameter measured by 2D echocardiography with the maximum diameter obtained from 3D echocardiography with multi-planar reconstruction and the maximum diameter from two angiographical incidences [3]. The results showed that 2D echocardiography measurements were significantly smaller.
than 3D and angiographical measurements. This underlines the accuracy of 3D in the quantitative assessment of the aortic annulus. As a supplement to angiographical measurements, 3D echocardiography with multiplanar reconstruction may reduce the tendency to undersize balloon choice. Due to the asymmetry of the aortic annulus, real-time 3D echocardiography may better capture its geometry and has to be considered as an additional technique for a multimodal assessment of the aortic root.

Adequate assessment of the aortic annulus diameter has other implications in surgery. The Ross procedure requires preoperative sizing of the annulus and good visualization of the aortic morphology [25,26]. Surgical aortic valve repair also requires the accurate measurement of aortic root dimensions to guide prosthesis selection, size and design.

Conclusions

This study shows the feasibility and reproducibility of real-time 3D-TTE in the measurement of the aortic annulus diameter. We also demonstrate for the first time in a standard paediatric population, mild but significant eccentricity of the aortic annulus. Real-time 3D echocardiography provides morphological but also quantitative information for the assessment of the aortic valve. Measurement of the asymmetry of the annulus may be recommended before percutaneous balloon valvoplasty or surgical valve repair.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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