

Comparison of 2D and 3D Echocardiographic Measurement of Mitral-Aortic Angle

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Abstract

The angle between the mitral and aortic valves (MAA) facilitates blood flow ejection in physiological condition. Also the narrowing of MAA increases the risk of systolic anterior movement. By convention, MAA is measured in the 2D echo image (2DE) representing the 3-chambers view (3-ch). However, changes in 3-ch view selection may lead to significant changes in the measured 2D angle, due to the 3D shape of the two annuli. Real-time 3D echo (3DE) represents an alternative way to study MAA. Accordingly, our aim was to measure the impact of minimal variation in 3-ch selection on MAA computation, compared to MAA measured with 3DE (MAA3D).

On 3DE data of 21 randomly chosen subjects, aortic and mitral annuli (AoA, MA) were traced using custom software. MAA3D was measured as the angle between the best fitting planes of the two traced annuli. To simulate 2D MAA measurements, the 3D data was sliced: 1) at the position corresponding to 3-ch; 2) using 20 translated planes (1mm step) on both sides of the 3-ch; 3) using 40 rotated planes (1 degree step) around MA saddle point. The intersection of the traced annuli with these planes was used to automatically measure MAA in 2D. Results showed that even slight misalignment ($>1\text{mm}$ and $>10^\circ$) of 2D cut-plane from the ideal 3-ch leads to MAA measures that differ from MAA3D.

1. Introduction

It is known that mitral valve (MV) and aortic valve (AV) are coupled through the fibrous tissue connecting them [1]. Consequently, it has been shown that MV and AV have synchronous dynamics, and alterations on one valve caused by pathology or intervention affect also the other [1,2,3]. These alterations could involve both functional changes and morphological deformations secondary to left ventricular (LV) remodelling.

Quantification of parameters describing the functional anatomy of the LV valves is a key factor in the assessment cardiac function. Many efforts have been made by the scientific community to develop new methods to extract such parameters from biomedical images. The continuously increasing use of 3D imaging technologies offered the possibility to improve the accuracy of the measurement at the base of anatomical structure characterization.

In particular, the introduction of 3D real-time echocardiography allowed non-invasive acquisition of

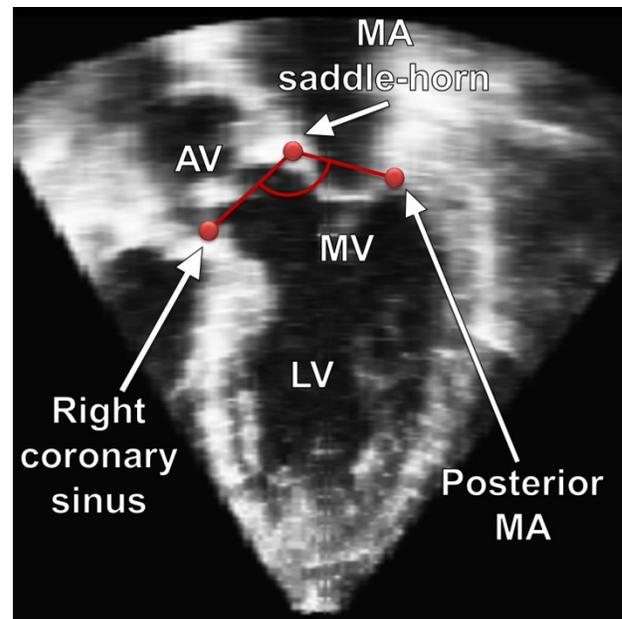


Figure 1. 2D measurement of mitral-aortic angle on apical 3-chamber view. MV: mitral valve, AV aortic valve, MA: mitral annulus, LV: left ventricle.

3D+time images of the beating heart. This imaging technology already showed its added value for the quantification of LV volume and valves morphology

[3,4]. However, 3D echocardiography is not yet adopted in clinical practice to measure mitral-aortic angle (MAA) for the evaluation of the reciprocal position of MV and AV. This angle is known to impact on blood ejection from LV to the circulatory system [1]. In addition, the narrowing of MAA is considered a potential cause of Systolic Anterior Motion (SAM) after MV annuloplasty with prosthetic annular ring [5], thus being an important parameter to assess with MV repair intervention and during follow-up.

Conventionally, 2D MAA is measured on the standard 2D apical 3-chamber view (figure 1) as the angle between: a) the line connecting posterior and anterior mitral annulus (MA) points and b) the line connecting anterior MA point and the further aortic annulus (AoA) point on the right coronary sinus. Anterior MA point is also the highest point (saddle-horn) of the saddle-shaped MA and the center point between the MV trigons. However, identification of 3-chamber view using 2D echocardiography can be affected by LV foreshortening or misalignment with LV long axis.

Accordingly, the aim of this work was to investigate possible causes of errors in the measurement of MAA using 2D images, and to assess the impact of minimal variation in 3-chamber selection for MAA measurement compared to real 3D MAA computation. In order to perform the comparison we used 3D echocardiographic dataset on which we measured 3D MAA and from which we extracted 2D slices to compute 2D MAA.

2. Methods

2.1. Mitral-aortic angle in 3D

Real-time 3D transesophageal echocardiographic data were acquired using Philips iE33 with X7 probe on 21 subjects. Inclusion criteria were good image quality and simultaneous acquisition of both MV and AV.

Considering that MV and AV are 3D structures, the definition of the angle between them may not be univocal. The principal function of cardiac valves is to separate two anatomical regions (i.e. left atrium and LV or LV and aorta). Consequently, we can geometrically represent a valve with a plane that separates the 3D space into two regions. Given this simplification, the angle between MV and AV is defined as the angle between the two planes that best fit the 3D line representing valve's annuli.

On the acquired 3D datasets, AoA and mitral annuli were traced at end-diastole using custom software. Following the procedure presented in [3], 20 points on MA and 24 points on AoA were identified on evenly rotated cross-sectional planes centered on MV and AV.

Manual correction was applied when necessary. Identified points were interpolated using cubic splines

representing MA and the three parts of AoA pertaining to right, left and non-coronary sinuses (figure 2). Best fitting plane for each valve was computed using least square minimization. Finally, 3D MAA was computed as the angle between the two fitting planes:

$$MAA = \cos^{-1}(\hat{n}_{MA} \cdot \hat{n}_{AoA})$$

where \hat{n}_{MA} and \hat{n}_{AoA} are the normal to the planes fitting MV and AV, respectively.

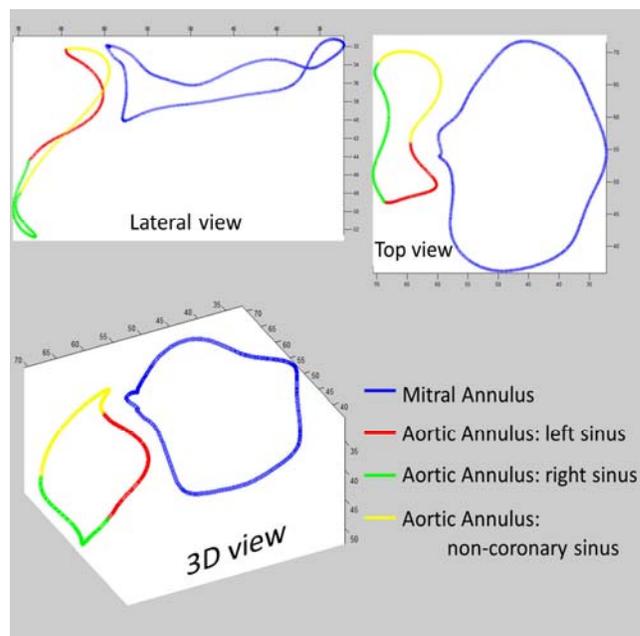


Figure 2. Traced 3D mitral annulus and aortic annulus after polynomial interpolation.

2.2. Mitral-aortic angle in 2D

From the same 3D datasets, several 2D cut-planes were extracted in order to simulate bi-dimensional acquisitions. The reference (i.e., correct) 3-chamber (3-ch) view was defined as the slicing plane orthogonal to MV and AV planes and passing through the MA saddle-horn.

To simulate incorrect 3-ch view identification the 3D data was sliced: 1) using 20 translated planes (1mm step) on both sides of the reference 3-ch view and 2) using 40 rotated planes 2 degree step apart from the reference 3-ch view around MA saddle point (figure 3). The intersection of the traced annuli with these planes was used to automatically identify anterior MA, posterior MA and right coronary sinus AoA points, needed to measure MAA in 2D.

Comparisons between 3D MAA and 2D MAA measurement were performed using paired student t-test. Differences were considered significant for $p < 0.05$.

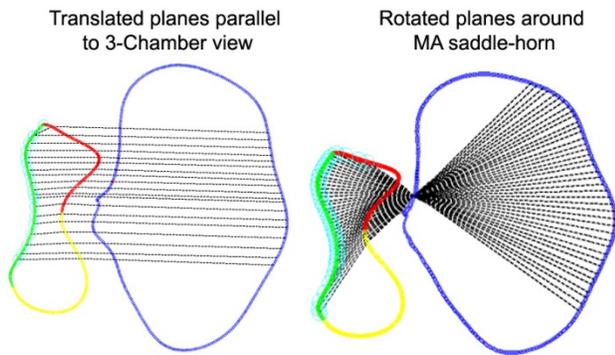


Figure 3. Planar view of MA and AoA with the 20 planes parallel to the reference 3-ch view (left) and the 40 planes rotated 20° clockwise and counter clockwise. Blu line is the MA, multicolour line is the AoA.

3. Results

Results are expressed as mean value \pm standard deviation. Measurement of MAA was feasible in all the subjects. On average, 3D MAA was $134.7^\circ \pm 9.2^\circ$ while 2D MAA on the reference 3-chamber view was $137.3^\circ \pm 12.0^\circ$. No significant differences were found among these two measurements. Correlation analysis between 3D MAA and 2D MAA on 3-chamber view showed a Pearson correlation index of $R=0.696$ with a mean difference of $2.6 \pm 8.6^\circ$.

2D MAA measured on translated planes ($\pm 10\text{mm}$) ranged from $127.3^\circ \pm 15.5^\circ$ to $158.1^\circ \pm 16.9^\circ$, while on rotated planes ($\pm 40^\circ$) ranged from $133.8^\circ \pm 10.7^\circ$ to

$148.3^\circ \pm 16.8^\circ$. 2D MAA was significantly different (paired t-test, $p < 0.05$) from 3D MAA already starting from translation greater than 1mm and rotation greater than 10° (figure 4). Correlation analysis between 3D MAA measurement and each one of the 2D MAA measurements resulted in best correspondence at +1mm for translated plane ($R=0.744$, mean difference= $-0.09 \pm 7.91^\circ$) and at +16° clockwise for rotated planes ($R=0.8$, mean difference= $-0.86 \pm 6.34^\circ$).

4. Discussions

MAA is an important parameter in order to assess MV and AV dynamic coupling. Reciprocal position of MV and AV in physiological conditions is considered to facilitate blood ejection [2]. Significant, even if small (8°) differences in MAA between normal and post-infarction subjects have been previously reported [6]. Also, wider MAA was found in presence of aortic stenosis and in case of systolic heart failure [4]. Importantly, it is recognized that narrowing of MAA as a consequence of annuloplasty causes SAM [5], a complex disorder that shifts the MV anteriorly during systole to impair cardiac performance.

MAA is measured non-invasively using 2D echocardiography on an apical 3-ch view. However, one of the limits of 2D echocardiography is that imaging the LV from an apical window frequently results in foreshortened views. Indeed, the imaging plane obtained through the intercostal space nearest to the LV apex may not contain the LV apex [7]. The foreshortening issue of 2D echocardiography principally affects the assessment of LV volume but also the measurement of MAA since

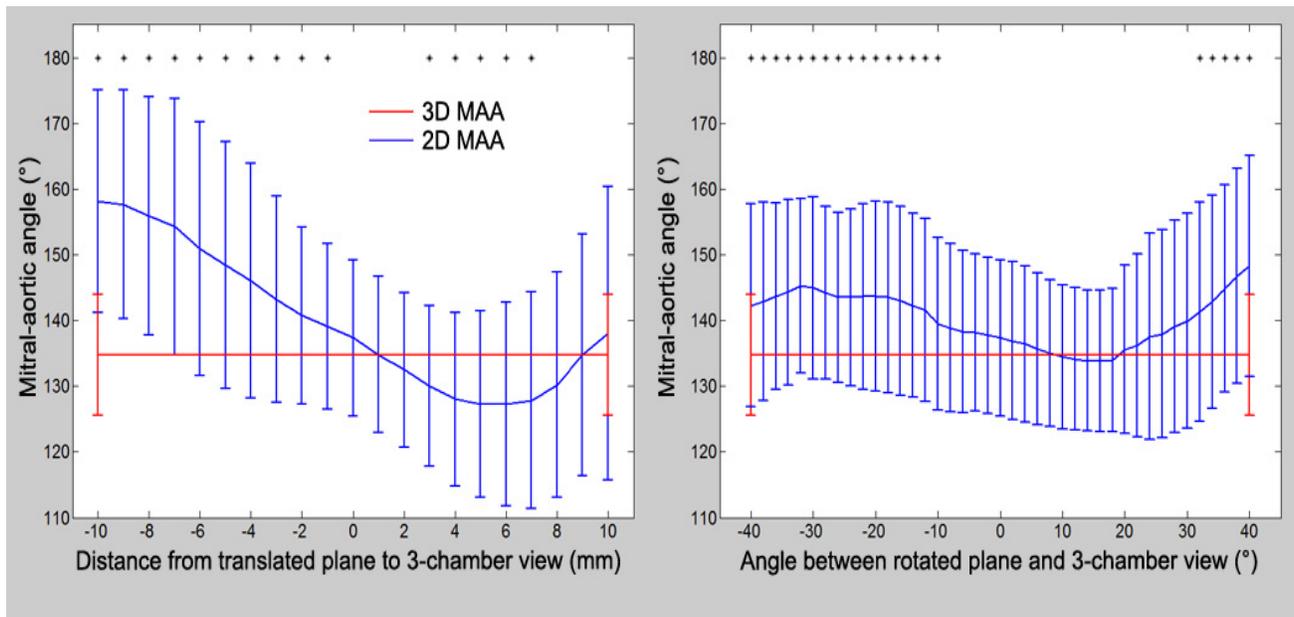


Figure 4. Differences between 3D MAA (red line) and 2D MAA on 3-ch parallel planes (left) and on 3-ch rotated planes (right). Error bars represent standard deviation. Dots on top on the plots indicate statistically significant differences between 3D and 2D measurements. It is possible to observe that differences start at 1mm for translated planes and from 10° for rotational planes.

oblique 3-ch view may lead to its over or under estimation. Real-time 3D imaging provides acquisition of the entire LV in the full volume scan, which allows for the identification of the anatomically correct non-foreshortened 3-ch view for MAA analysis. In this paper the discrepancies between measurements obtained using 2D and 3D techniques are presented.

Our results showed that there is no statistical difference between MAA measured on the reference 3-ch view (extracted as 2D cut-plane from the volumetric dataset) and using 3D echocardiography, showing that accurate definition of 3-ch view in 2D images lead to measurements of MAA compatible with the ones in 3D with the proposed technique. However, the best concordance between the two techniques was found at +1mm translation and at +16° clockwise rotation. This difference could be due to the 3D nature of the MV and AV, as the angle between these two structures in 2D does not take into account the 3D valvular shapes.

On the contrary, when the 2D cut-plane on which MAA is measured is slightly not aligned with the reference 3-ch view, differences with 3D MAA became significant. As expected, these differences were not linearly increasing with the distance from the 3-ch reference plane because of the saddle shape of MA and the crown shape of AoA (figure 2). Considering that 2D echocardiography is also limited by higher intra and inter operator variability than other imaging modalities (CT, MRI), the narrow limit of agreement for MAA measurement that we found between reference and slightly misaligned planes, will not allow high accuracy.

3D echocardiography in this scenario provides a double advantage: 3D data can be either sliced by the user in order to identify the proper 3-ch view using the help of the multi-planar visualization, or analysed as a whole by proper software that allows for 3D quantification. For the second case several studies showed the feasibility of this measure [3,4,8] on 3D real-time echocardiography. It is important to notice that, at the moment, the two main software tools on the market for off-line 3D echo analysis (Qlab by Philips and 4D MV-Assessment by TomTec Imaging) measure MAA considering the 3D shape of the MA and just one point on the AoA, thus being prone to inaccurate measurement of the angle between the two valves in case of AV deformation, stenosis or prosthesis implantation. The precision of this measurement of MAA using just one point to characterize AV position with respect to MV should be further investigated.

5. Conclusions

MAA is a parameter that can be helpful for the prevention of systolic anterior motion and to characterize mitral-aortic coupling. Our results showed that despite good correlation between MAA measurement on 2D reference 3-ch cut-plane and 3D volumetric data, slight

misalignment of the cut-plane (i.e. in a clinical scenario of the 2D scan plane) from the ideal 3-ch view leads to significant differences in MAA. Consequently, 3D echocardiography should be preferred to 2D for the assessment of the angle between MV and AV.

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