Estimates of mitral-aortic angle measurement errors in 2D compared to 3D echocardiography

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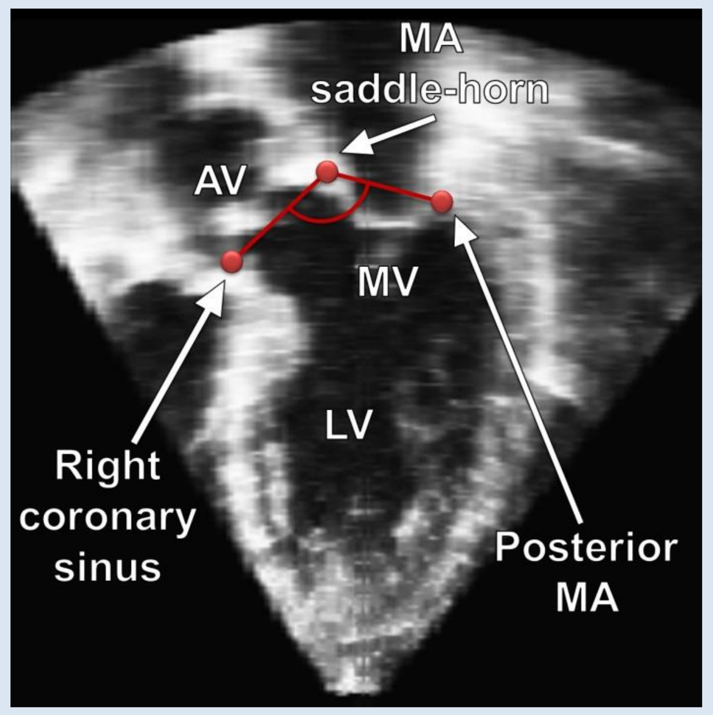
Background

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) 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.



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

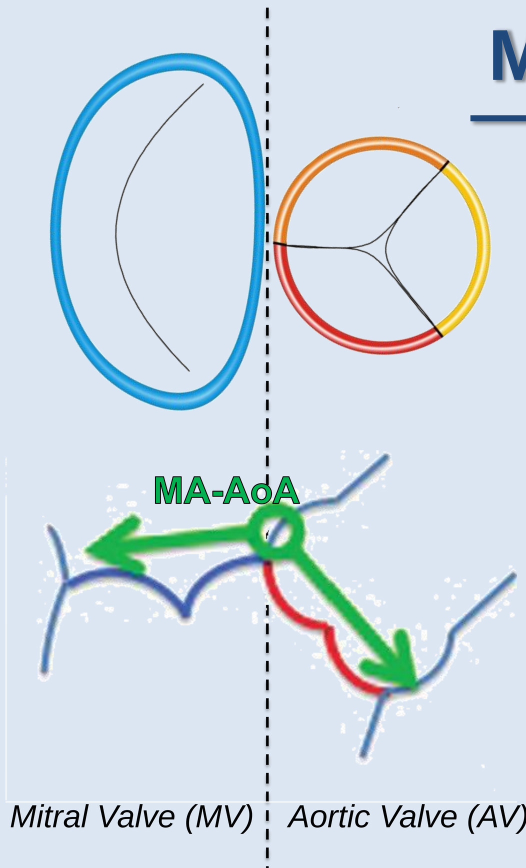
Aim

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.

Patient Population

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.

Mitral-Aortic Angle



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.

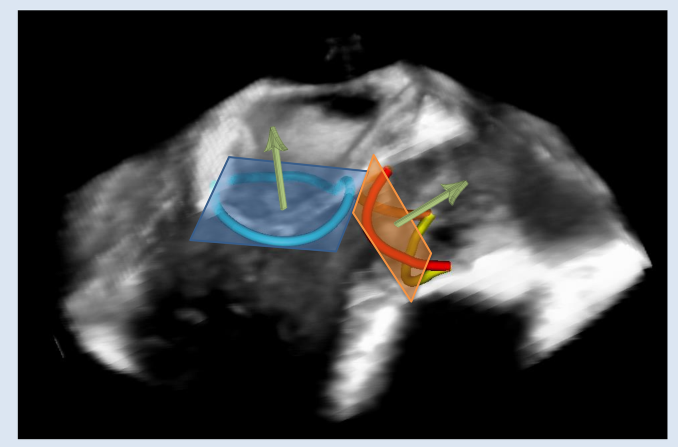
Methods

Mitral-Aortic Angel in 3D

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.

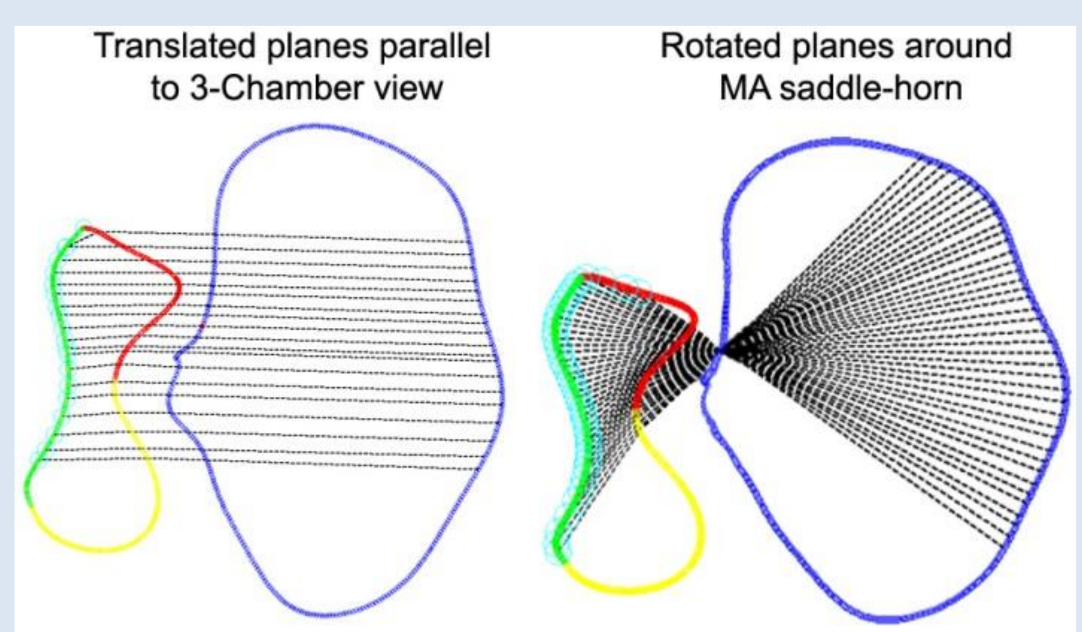


Mitral-Aortic Angel in 2D

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.

Statistical analysis

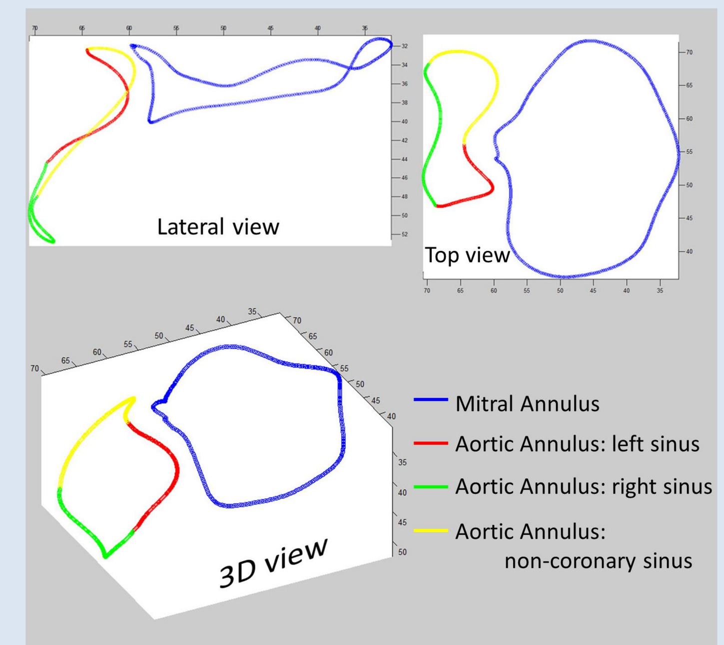
Results are expressed as mean value ± standard deviation. Comparisons between 3D MAA and 2D MAA measurement were performed using paired student t-test. Differences were considered significant for $p<0.05$.



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.

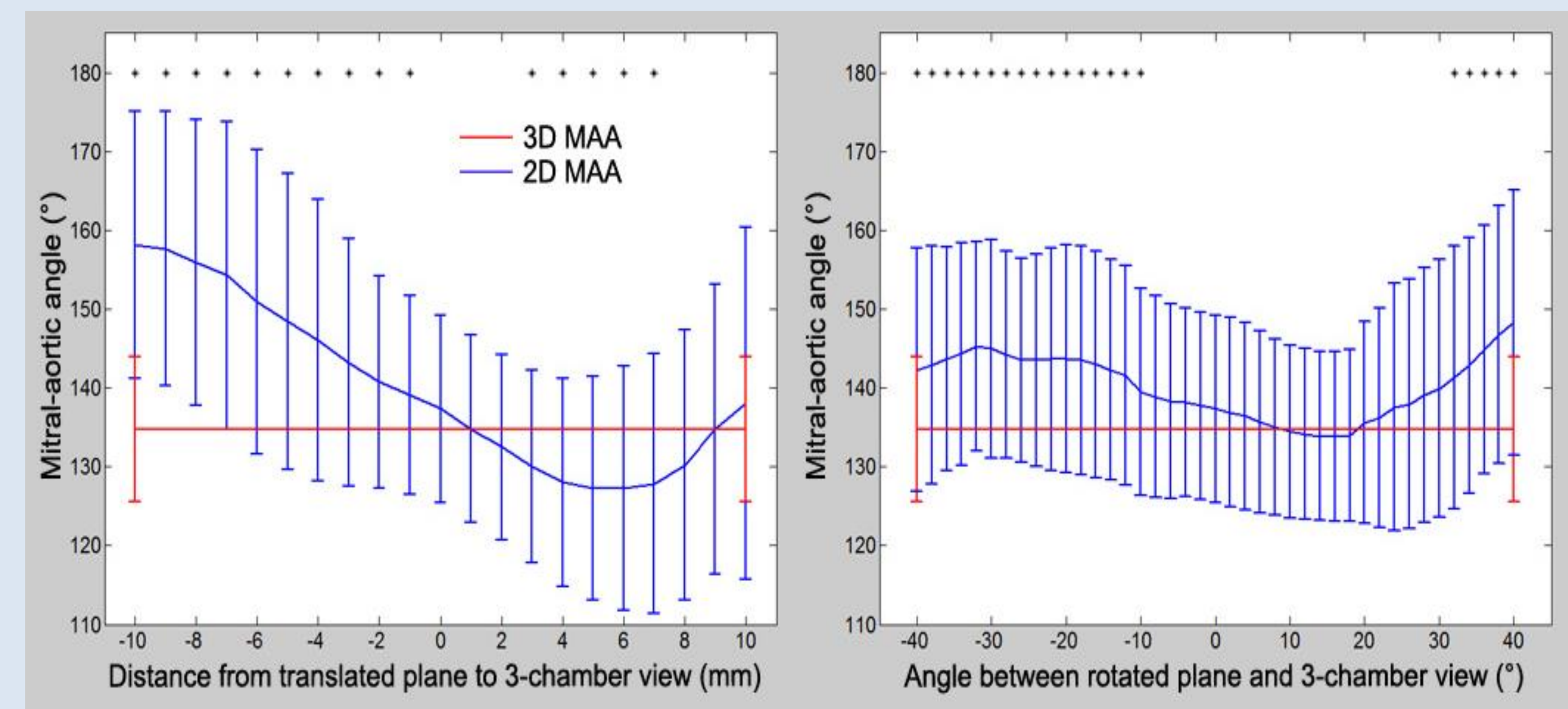
Results

Results are expressed as mean value ± standard deviation. Measurement of MAA was feasible in all the subjects. On average, 3D MAA was 134.7°±9.2° while 2D MAA on the reference 3-chamber view was 137.3°±12.0°. 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±8.6°.



Traced MA and AoA after polinomial interpolation. Note that MA is saddle-shaped while AoA is crown-shaped.

2D MAA measured on translated planes (±10mm) ranged from 127.3°±15.5° to 158.1°±16.9°, while on rotated planes (±40°) ranged from 133.8°±10.7° to 148.3°±16.8°. 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±7.91°) and at +16° clockwise for rotated planes (R=0.8, mean difference=0.86±6.34°).



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.

Conclusions

MAA is a parameter which assessment 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.