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Advanced Technologies in the Quantification of Mitral Valve

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Abstract

The current study aimed at conducting an educational survey on the mitral valve using advanced technologies eSie Valve[®] and Q-Lab in echocardiography machines and also those mitral valve geometrical parameter measurements that can be easily calculated with MATLAB software offline in a personal computer as an echocardiographic desk for further information and recommendation before mitral valve repairs or other treatments.

INTRODUCTION

The mechanics of the mitral valve leaflet as nonlinear, inflexible, and anisotropic soft tissue consequence from a combined reaction of many mathematical/physical indices. In the past decade, partial differential numerical modeling of complete heart valves made a good understanding in heart valve surgery, a design of prosthetic valve replacements, and also a general consideration of healthy and abnormal cardiac function. Such a model should be based on a precise description of the automated assessable behavior of the valve. Echocardiography is the best method for the morphology of the heart valves. The practical use of ultrasound techniques is straightforward and its quantitation can be simplified. Echocardiography suggests not only live images of the beating heart for inspection, but also the ability to perform measurable analysis on fixed frames per a cardiac cycle and, more recently, dynamic quantification from moving images. Geometrical measurement analyses play the main roles to achieve the mitral valve ailments. They are used to make the best understanding of valve anatomy, pathology, function, and the structure of the mitral valve diseases. Echocardiographic techniques are the best

methods to calculate the quantitative data that are comparable to straight anatomic measurements and surgical tasks.

Methods to Quantify Mitral Valve

The current study was divided into three main phases in order to quantify mitral valve form, structure, and function as follows:

- 1- Geometrical mitral valve parameters
- 2- eSie Valve[®] and Q-Lab package (applied to mitral valve parameters measurements)
- 3- Utilizing mathematical equation and MATLAB software (a simple echocardiographic desk) (to measure the geometrical mitral valve variables offline based on 2D or 3D conventional echocardiographic images)

Geometrical Mitral Valve Parameters

The modeling techniques proposed in the current study were intended to show the role of geometrical parameters (Figs 1 and 2) of the mitral valve to gain a better understanding of the MV and assist them in obtaining a reliable orientation in order to choose treatment strategies and plan surgical interventions.

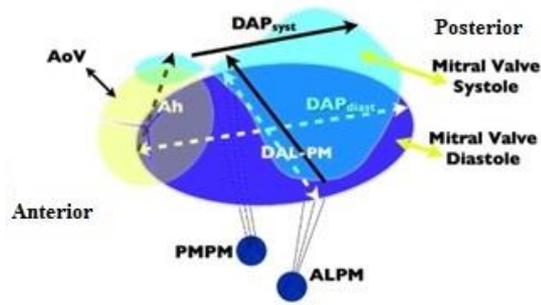


Figure 1: A Schematic Shape of Mitral Valve Components; the Blue Region is in the Mitral Valve Diastole. The Green Region shows the Mitral Valve in Systolic Phase. The Intercommissural Diameter (DAL-PM) (Normal Range 18.7 mm (16.5-19.7); AH, Annular Height (Normal Range 4.4 mm (3.6-5.4); DAP, Anteroposterior Diameter (Normal Range 16.4 mm (15.1-17.8))

To study the bending behavior of the mitral valve leaflets, there are several angle dependent variables such as the anteroposterior at the coaptation level in systole (normal range 140 (127-149), the anteroposterior at the commissural level in systole (normal range 126 (113-137), and the anteroposterior at the commissural level in diastole (normal range 115 (104-129); however, the anterior leaflet bending angle (sometimes called anterolateral angle) in systole (normal range 119 (106-130) and diastole (normal range 105 (97-113) should also be considered [1]. The other common quantitative mitral valve parameters are annular height (normal

range 4.4 mm (3.6-5.4), coaptation length (normal range 29.9 ± 6.6 mm), coaptation depth, tending height (normal range 1.59 mm (1.1-2.24), tending volume (normal range 0.29 mL (0.12-0.41), posterior prolapse height (normal range 0.7 mm (0.39-1.14), and posterior prolapse volume (normal range 0.05 mL (0-0.21) [2, 3].

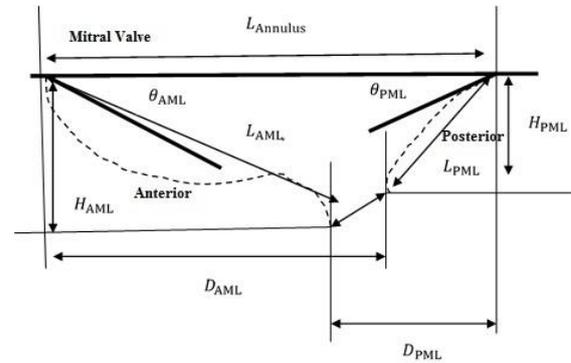


Figure 2: A Schematic Design of the Geometrical Parameters of the Mitral Valve

The Mitral-aortic Angles

The angle between the mitral and aortic annuli (normal range $118^\circ \pm 8^\circ$) (Fig 3) and the angle between the intersection of lines passing through the midpoints of the mitral and aortic valves (normal range $60^\circ \pm 6^\circ$) (Fig 3) are the two very important angles to help predicting the risk of systolic anterior motion of the mitral leaflets [4].

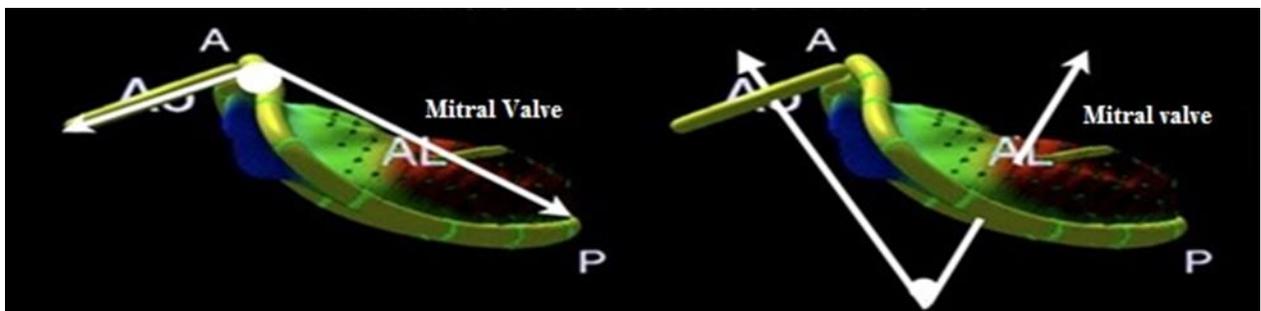


Figure 3: Mitral-Aortic Angles

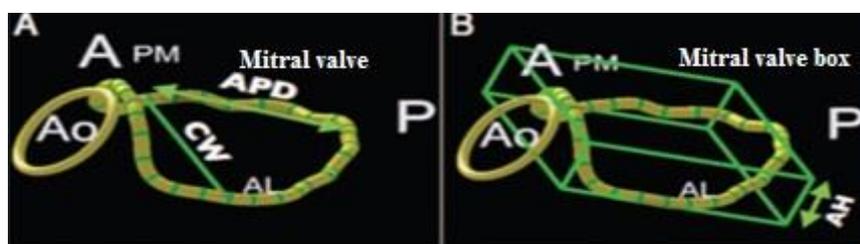


Figure 4: Annular Height and Commissural Width to Provide AHCWR Index

Annular Height to Commissural Width Ratio (AHCWR)

The saddle shape of the mitral valve annulus can be evaluated/ interpreted by the annular height (AH) (7.9

± 1.9 mm) to commissural width (CW) (normal range 33 ± 3.7 mm) ratio of the mitral valve named AHCWR (normal range $23.7\% \pm 5.4\%$) (Fig 4) [4].

Circularity Index

It is a ratio derived from AP diameter (the distance between the anterior and posterior landmarks) and AL-PM diameter (distance between anterolateral and posteromedial landmarks) and is automatically generated for normal range ($0.90\% \pm 0.1\%$) (Fig 5) [5].

The eSie Valve[®] and Q-Lab Package

The eSie Valve[®] and Q-Lab package rely on an advanced machine learning technology to professionally assess a

complete model of the mitral and aortic valves using 2D or 3D transesophageal echocardiographic (TEE) images. Naturally, a surface model of the valves is fixed to a TEE image using the knowledge learned from a large database of annotated images. For dynamic analysis, a tracking algorithm is employed to estimate a moving valve model throughout the cardiac cycle for quantitative valve analyses [6].

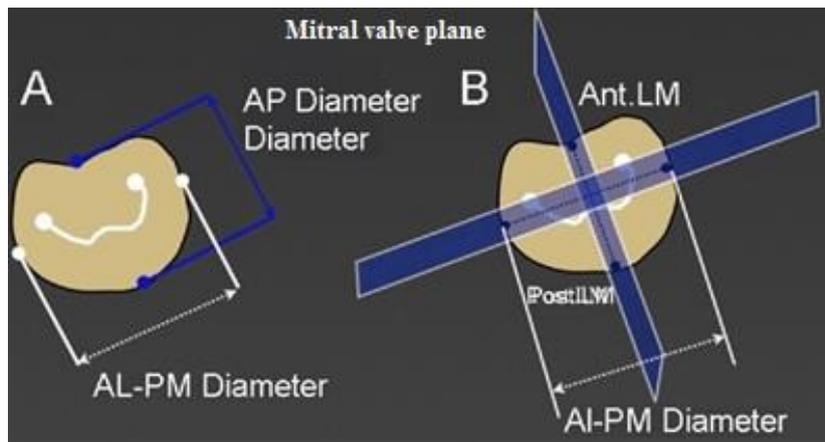


Figure 5: Parameters Measured for the Circularity Index

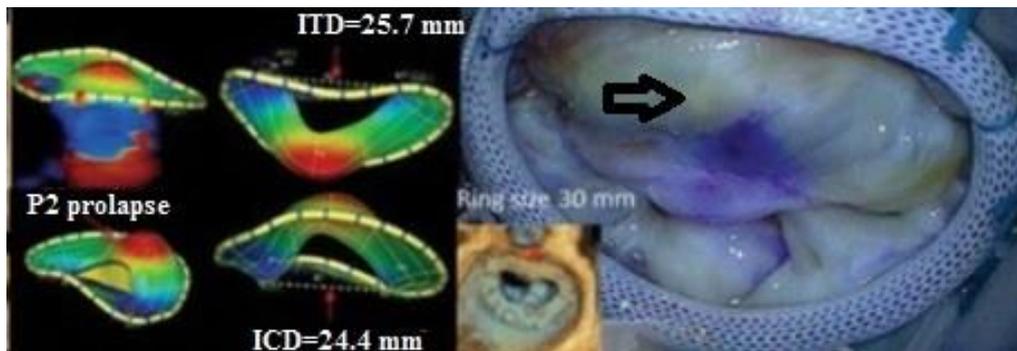


Figure 6: The eSie Valves' Package Models a Valve; a Mitral Valve with Severe Posterior Prolapse with a clearly identified P2 Prolapse.

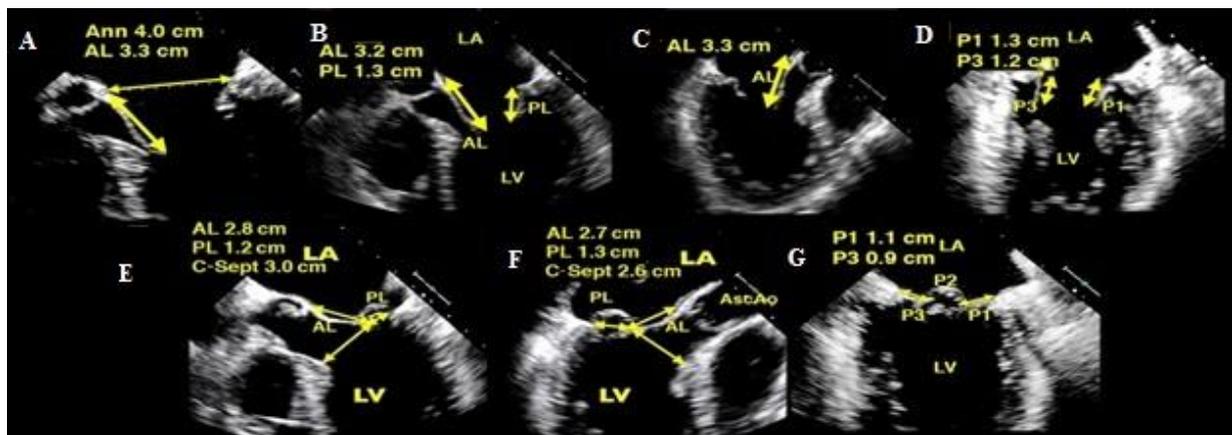


Figure 7: Measurements in Q-Lab: Figures A, B, C, and D are acquired from the Midesophageal 4-/5-Chamber, the LAX, and the Two-chamber Views throughout Ventricular Diastole. Figures E, F, and G are the Consistent Figures Achieved during Ventricular Systole. For this Patient, the Risk of SAM is considered low based on a C-Sept distance >2.5 cm and an AL/PL ratio >1.0 with Relatively Small P1 and P3 (< 1.4 cm). Ann, Annulus; AL, Anterior Leaflet; PL, Posterior leaflet; LA, Left Atrium; LV, Left Ventricle; C-Sept, the Distance between the Coaptation Point and Ventricular Septum; P1, P2, P3, 3 Scallop of the Posterior Leaflet

Each Valve is Parameterized by Three Levels of Details

The first one expresses the region of interest (ROI), where the valve is situated within the image, specifically valve position (center of the ROI), scale (size of the ROI), and orientation. The second, key anatomical points are then defined within the ROI (second level of details). These points are anatomically unique and can be recognized in the images. In the third level of details, symbolized surface models of the valve (mitral leaflets) pass through the points that all mentioned measurements can be calculated automatically from the valve model (e.g. A1 area: 159.8 mm², A2 area: 264.8 mm², and A3 area: 136.5 mm²). With the eSie Valve[®] and Q-Lab package, the mitral annulus circumference is also a good predictor for ring size, along with intercommissural distance ($r = 0.83$ and 0.80 respectively, all measurements were indexed by body surface area) (Fig 6 and 7) [7-14].

3- Utilizing mathematical equation and MATLAB software (a simple echocardiographic desk)

By utilizing a mathematical equation and MATLAB software, the geometrical mitral valve variables can be measured based on 2D conventional echocardiographic images.

Tip and tricks to present an echocardiographic image inside the MATLAB software:

First the MATLAB software should be opened; then the command `pic = imread ('')` written down in the command window. This command can be used to read a photo from the computer. The image address, image name, and photo extensions should be written in parentheses. For example, if the echocardiographic image is in the following address: C:\Users\USER\Desktop\echo image 1.jpg, this command should be written as: `pic = imread ('C:\Users\USER\Desktop\echo image 1.jpg')`; finally, the image should be called by `imshow (pic)` command, and then saved by the program and clicking the RUN button. A new window is opened and the searched image is displayed. The distances of the image can be edited or measured by the menus above this observed image (Fig 8).

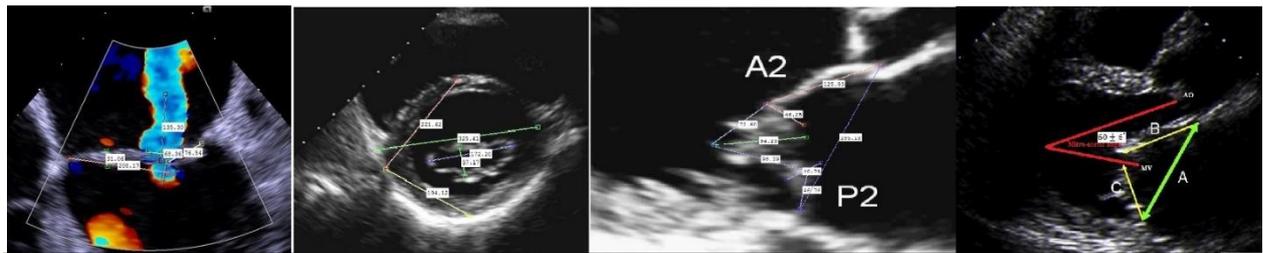


Figure 8: Mitral Valve Measurements Based on Echocardiographic Images as the Inputs in MATLAB Software

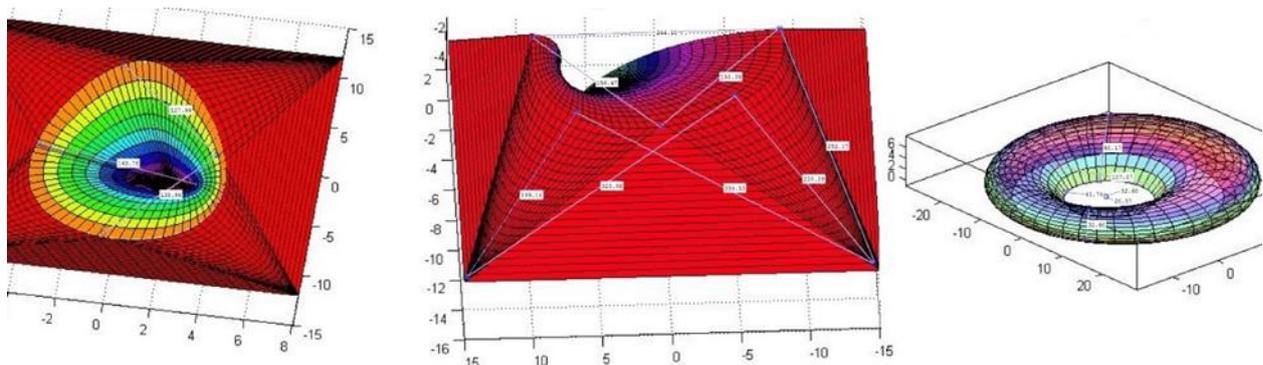


Figure 9: 3D Reconstructions/Measurements of a Mitral Valve Based on Mathematical Equations and the Geometrical Mitral Valve Parameter Measurements in MATLAB Software

Afterward, when each echocardiographic image at the level of mitral valve was displayed in the MATLAB software, all sizes were measured. In each plane and for each frame during diastole to systole, mitral valve annulus and leaflets, bases, middles, and tips of AML and PML were manually identified using MATLAB software. Then, 3D MV annulus geometry, leaflets measurements, and AML and PML positions were automatically computed for each frame and used as

input for displacement vectors modeling of the mitral valve leaflets. By solving mathematical equations of inelastic properties of leaflets, each plane was replaced with 60 vectors of displacement and ultimately the mitral valve leaflets were realized by 1125 vectors of displacements, where they also show translations, rotations, and pure strains of bases, middles, and tips of AML and PML simultaneously per cardiac cycle and

finally, a mitral valve mathematical modeling (Fig 9) [15, 16].

CONCLUSIONS

In spite of the introduced methods applied for echocardiographic datasets at the level of mitral valve for practical applications and clinical verifications, the ideas developed in this article have obvious applications in many areas and the other systems of cardiovascular imaging. The most important applications, however, may be pedagogical. A computer desk (online or offline) can help an echocardiographer to work on the echocardiographic images to evaluate the data.

Conflicts of Interest

The authors declared no conflict of interest.

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