Using Anatomic Intelligence to Localize Mitral Valve Prolapse on Three-Dimensional Echocardiography

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Background: Accurate localization of mitral valve prolapse (MVP) is crucial for surgical planning. Despite improved visualization of the mitral valve by three-dimensional transesophageal echocardiography, image interpretation remains expertise dependent. Manual construction of mitral valve topographic maps improves diagnostic accuracy but is time-consuming and requires substantial manual input. A novel computer-learning technique called Anatomical Intelligence in ultrasound (AIUS) semiautomatically tracks the annulus and leaflet anatomy for parametric analysis. The aims of this study were to examine whether AIUS could improve accuracy and efficiency in localizing MVP among operators with different levels of experience.

Methods: Two experts and four intermediate-level echocardiographers (nonexperts) retrospectively performed analysis of three-dimensional transesophageal echocardiographic images to generate topographic mitral valve models in 90 patients with degenerative MVP. All echocardiographers performed both AIUS and manual segmentation in sequential weekly sessions. The results were compared with surgical findings.

Results: Manual segmentation by nonexperts had significantly lower sensitivity (60% vs 90%, $P < .001$), specificity (91% vs 97%, $P = .001$), and accuracy (83% vs 95%, $P < .001$) compared with experts. AIUS significantly improved the accuracy of nonexperts (from 83% to 89%, $P = .003$), particularly for lesions involving the A3 (from 81% to 94%, $P = .006$) and P1 (from 78% to 88%, $P = .001$) segments, presumably related to anatomic variants of the annulus that made tracking more challenging. AIUS required significantly less time for image analysis by both experts (1.9 ± 0.7 vs 9.9 ± 3.5 min, $P < .0001$) and nonexperts (5.0 ± 0.5 vs 13 ± 1.5 min, $P < .0001$), especially for complex lesions.

Conclusions: Anatomic assessment of mitral valve pathology by three-dimensional transesophageal echocardiography is experience dependent. A semiautomated algorithm using AIUS improves accuracy and efficiency in localizing MVP by less experienced operators. (J Am Soc Echocardiogr 2016;■:■-■.)

Keywords: Mitral valve, Computer imaging, Three-dimensional echocardiography, Transesophageal echocardiography

Preoperative assessment of the mitral valve (MV) is crucial for planning surgical repair strategy for mitral regurgitation. Accurate localization of segmental MV prolapse (MVP) has implications in reparability and thus timing of surgery and choice of surgeons.[1,2] Three-dimensional (3D) transesophageal echocardiographic (TEE) imaging has been shown to be superior to two-dimensional (2D) TEE imaging in localizing MVP with good surgical agreement.[3,4] However, visual diagnosis of MVP on the volume-rendered images requires training and experience to distinguish normal anatomy, pathology, and artifact. In particular, interpretation of prolapse involving A1, P1, A3, and P3 is often erroneous by readers with less experience with 3D echocardiography.[3,5-7]

The interpretation of MV topographic maps has been shown to improve the diagnostic accuracy of less experienced readers, surpassing 2D and 3D (volume-rendered) TEE images.[8] Nevertheless, the process of construction of an MV topographic map is cumbersome and time-consuming, requiring operators to be familiar with the many variations of normal MV anatomy and pathology. Because the

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This work is partially supported by the General Research Fund of the Research Grant Committee of Hong Kong (467812).

Dr. Lee has received a speaking honorarium and research grant support from Philips Healthcare. Drs. Salgo and Schneider are employees of Philips Healthcare. Other authors reported no conflict of interest.

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0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2016.07.002

Abbreviations
AIUS = Anatomical Intelligence in ultrasound
MV = Mitral valve
MVP = Mitral valve prolapse
TEE = Transesophageal echocardiographic
3D = Three-dimensional
2D = Two-dimensional

process involves many manual steps to define anatomic landmarks, substantial measurement bias, errors, and variability could be introduced.[9] Therefore, 3D topographic maps of the MV, despite their potential diagnostic utility, have not been routinely adopted for clinical use.

Recently, a novel computer-learning algorithm called Anatomical Intelligence in ultrasound (AIUS) was developed, which can segment the images obtained by using an ultrasound device in a semiautomatic manner on the basis of an individual patient's anatomy.[10] AIUS has been reported to provide accurate, reproducible, and rapid quantification of MV anatomy by minimizing manual input.[11] Accordingly, the aims of this study were (1) to examine whether AIUS improves diagnostic accuracy and efficiency in localizing MVP compared with a manual approach and (2) to determine whether the operator's level of training in echocardiography influences the usefulness of AIUS on the accuracy of the 3D TEE localization of MVP.

METHODS

Patient Population

This was a retrospective study of patients with severe mitral regurgitation who were referred clinically to our echocardiography laboratory for preoperative TEE evaluation for MV repair. At our institution, detailed preoperative 3D TEE study of valve morphology is performed for preoperative planning in all patients undergoing MV repair within 2 weeks before surgery. From January 2009 to December 2013, a total of 106 patients at our institution underwent preoperative TEE evaluation for MV repair. Of these 106 patients, 16 were excluded from the present study because of associated mitral stenosis, functional mitral regurgitation, aortic valve disease, and/or previous endocarditis. The final analysis included 90 patients (mean age, 60 ± 10 years; 38 women) undergoing MV repair for severe symptomatic mitral regurgitation due to MVP. The feasibility of AIUS was reported in 33 patients with MVP in our previous study.[11] Of these initial 33 patients, 24 patients underwent MV repair and were included in the present analysis. The localization of MV pathology in the patients with mitral regurgitation was confirmed by surgical exploration. The institutional review board approved the study.

Three-Dimensional Image Acquisition

A standardized 3D TEE imaging protocol for MV evaluation has been in place in our echocardiography laboratory since late 2008. An iE33 or EPIQ7 ultrasound system (Philips Healthcare, Andover, MA) equipped with a fully sampled matrix transducer (X7-2t) was used to obtain real-time 3D TEE images of the MV. Midesophageal zoomed 3D TEE images of the MV apparatus were acquired. The region of interest was adjusted to the smallest pyramidal volume that encompassed the MV. Multibeat gated acquisition mode was used in patients in sinus rhythm. If there was stitching artifact in the initial 3D data sets, acquisition was repeated until optimal images without stitching artifact were obtained. All images were stored digitally in raw-data format. The high–volume rate single-beat acquisition protocol was used in patients with atrial fibrillation to avoid stitching artifact as a result of irregular rhythm while maintaining adequate volume rate. The index-beat method proposed by Kusunose *et al.*[12] was used to select the cardiac cycle for analysis in patients with atrial fibrillation: five to 10 beats of volumetric data sets were captured for atrial fibrillation, and the beat with roughly equal preceding and pre-preceding beat intervals was used for 3D analysis. Volume rates for both techniques was maximized to >15 Hz.

MV Topographic Model Construction and Interpretation

All 3D TEE images were transferred to two independent Xcelera workstations (Philips Healthcare) for construction of the MV topographic models, with a software package using the manual technique (Mitral Valve Quantification) installed on one and an AIUS software package (Mitral Valve Navigation) installed on another. The manual approach for MV reconstruction involved manual definition of the end-systolic frame, manual alignment of the image planes, placement of annular markers on multiple radial planes, and tracing of leaflet contour and coaptation on multiple parallel planes, as previously described.[13] The semiautomatic creation of the MV topographic model by AIUS begins with automatic end-systolic frame identification on the basis of waveform analysis of the electrocardiogram. After image alignment under schematic guidance, four mitral annular reference points, the aorta, and the coaptation nadir were tagged to initiate a semiautomatic annular track and leaflet trace. The line of coaptation was delineated by manual placement of markers on the coaptation points on multiple parallel long-axis planes. A color-coded topographic map of the MV was then generated. The colors were coded to display leaflet displacement into the left atrium from the annular plane at end-systole, with red indicating leaflet position above the annular plane and blue indicating leaflet position below the annular plane. The parametric map also displays the amplitude and location of the maximal leaflet displacement into the left atrium. The more displacement a lesion has, the brighter the red color is on the parametric map. Prolapse is defined as leaflet displacement > 1 mm above the annular plane, as previously validated against surgical inspection.[14] Similarly, in multisegment prolapse, AIUS detects the entire leaflet surface and color-codes all lesions with >1 mm systolic displacement above the 3D annular plane as red. When there is a coaptation gap due to flail leaflet, the coaptation markers can be manually edited to separately locate the two tips of anterior and posterior leaflets (Figure 1).

Two experienced American Society of Echocardiography level 3 (or equivalent) echocardiographers (experts) with extensive 3D experience (having performed Mitral Valve Quantification in >500 cases)[13] and four intermediate-level operators (nonexperts) with level 2 or equivalent training with minimal (<10 cases) previous 3D MV analysis experience were asked to perform offline MV topographic model construction using both the manual and AIUS techniques. The nonexperts underwent brief training on the operation of both Mitral Valve Quantification and Mitral Valve Navigation in 10 separate cases. All investigators were blinded to the measurements performed by others and to the clinical data. Manual and AIUS analyses were separately performed ≥1 week apart. The total time spent on each method for each case was recorded for both approaches. In 30 randomly selected data sets, two nonexperts performed AIUS and manual analysis to assess interobserver variability. One of the operators repeated the analyses 1 week later to assess intraobserver variability. Two experts repeated the same process to determine reproducibility among experts.