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Live 3-Dimensional Transesophageal Echocardiography

Initial Experience Using the Fully-Sampled Matrix Array Probe

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Objectives Our study goals were to evaluate the 3-dimensional matrix array transesophageal echocardiographic (3D-MTEE) probe by assessing the image quality of native valves and other intracardiac structures.

Background Because 3-dimensional transesophageal echocardiography with gated rotational acquisition is not used routinely as the result of artifacts, lengthy acquisition, and processing, a 3D-MTEE probe was developed (Philips Medical Systems, Andover, Massachusetts).

Methods In 211 patients, 3D-MTEE zoom images of the mitral valve (MV), aortic valve, tricuspid valve, interatrial septum, and left atrial appendage were obtained, followed by a left ventricular wide-angled acquisition. Images were reviewed and graded off-line (Xcelera with QLAB software, Philips Medical Systems).

Results Excellent visualization of the MV (85% to 91% for all scallops of both MV leaflets), interatrial septum (84%), left atrial appendage (86%), and left ventricle (77%) was observed. Native aortic and tricuspid valves were optimally visualized only in 18% and 11% of patients, respectively.

Conclusions The use of 3D-MTEE imaging, which is feasible in most patients, provides superb imaging of native MVs, which makes this modality an excellent choice for MV surgical planning and guidance of percutaneous interventions. Optimal aortic and tricuspid valve imaging will depend on further technological developments. Fast acquisition and immediate online display will facilitate wider acceptance and routine use in clinical practice. (J Am Coll Cardiol 2008;52:446–9) © 2008 by the American College of Cardiology Foundation

Transesophageal echocardiography (TEE) is an indispensable tool for cardiologists and cardiac anesthesiologists worldwide. Since the introduction of a TEE probe with a single-crystal M-mode transducer allowing unidimensional imaging, the TEE probe has evolved into a clinically valuable diagnostic tool used for the comprehensive examination of cardiovascular abnormalities (1–3). Currently, 3-dimensional (3D) TEE is performed with a multiplane probe using a rotational approach for sequential data acquisition, gated to electrocardiography (ECG) and respiration (4–7). From these 3D volume datasets, any desired cut-plane can be derived and structures of interest rendered. Unfortunately, this technique is limited by lengthy data acquisition, frequent radial artifacts, and the need for offline processing (8). Consequently, 3D reconstruction TEE has not been embraced routinely in clinical practice and is at this time predominantly used for research.

To overcome these limitations, a 3D fully-sampled matrix array TEE (3D-MTEE) transducer was recently developed to allow real-time acquisition and online display of 3D images. This probe combines novel electronic circuitry with miniaturized beam-forming technology in the tip of an otherwise conventional TEE probe. This report represents the first study to evaluate this new technology in a clinical environment by assessing the feasibility and quality of visualization of different cardiac structures, including native valves, interatrial septum (IAS), left atrial appendage (LAA), and the left ventricle (LV), in a large number of consecutive patients.

Methods

Real-time 3D transesophageal imaging. We performed imaging by using an iE33 ultrasound system (Philips

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Medical Systems, Andover, Massachusetts) that was equipped with a fully-sampled 3D-MTEE transducer. This transducer uses approximately 3,000 elements, in contrast to the 64 elements currently used in the multiplane TEE probe (i.e., Omni III, Philips Medical Systems). Initially, gain settings were optimized with the narrow-angled acquisition mode (live 3D), which allows real-time 3D imaging without the need for ECG gating. This mode displays a pyramidal volume of approximately 30° × 60°. The 3D zoom mode, which displays a smaller, magnified pyramidal volume, was subsequently used to image different cardiac structures, including native valves, fossa ovalis, and the LAA. In addition, the LV was imaged with the full-volume mode gated to ECG, which acquires 4 narrower wedges of volume over 4 consecutive heart beats, resulting in a wider pyramidal volume (65° × 56° up to 102° × 105°). Images were reviewed offline on an Xcelera workstation with the use of QLAB software (Philips Medical Systems).

Study design. Two hundred eleven patients (110 men; mean age 61 ± 12 years) were studied during clinically-indicated TEE examinations according to standard protocol, including patients with atrial fibrillation (21 of 211, 10%). Patients with prosthetic valves and/or post-MV repair were excluded. Real-time zoom mode images of the native MV, aortic valve (AV), tricuspid valve (TV), IAS, and LAA were obtained in each patient, followed by a wide-angled acquisition of the LV. Patients were recruited from the University of Chicago Medical Center and the Brigham and Women's Hospital. The research portion of the study was approved by the institutional review boards of both institutions. Written informed consent was obtained at the time of consent for the clinical TEE procedure. After completing the clinical portion of the 2-dimensional TEE study, a real-time 3D TEE study targeted toward visualizing different cardiac structures was performed.

Images were reviewed by 2 independent observers from both ventricular and atrial perspectives for the MV and TV, LV outflow tract and aortic perspectives for the AV, and from the LA and right atrial perspectives for the IAS. The LAA was visualized en-face as well as on cross-sectional long-axis view. The LV was cropped to provide multiple cross-sectional views to allow the assessment of endocardial visualization of all ventricular walls. Each observer graded the quality of visualization for each cardiac structure: 0 = inadequate visualization, 1 = at least 75% visualization and motion artifact, and 2 = >75% visualization, without dropout or motion artifacts. Each scallop of the MV was scored individually, including anterior (A1, A2, A3) and posterior (P1, P2, P3) leaflet scallops. Similarly, the noncoronary and left and right coronary cusps of the AV were scored individually. The TV leaflets were not scored independently because of their generally limited visualization. The scores of the 2 observers were averaged.

Results

Successful intubation was achieved in all 211 patients without complications. Acquisition of the real-time 3D-MTEE data was accomplished in approximately 10 min. Figure 1 shows 3D images of the mitral and aortic valves in systole and diastole. Figures 2 shows examples of 3D images of the LAA and left upper pulmonary vein, visualized en-face and in the long-axis view (Figs. 2A and 2B, respectively) and the interatrial septum (Fig. 2C).

Abbreviations and Acronyms

AV = aortic valve
IAS = interatrial septum
LAA = left atrial appendage
LV = left ventricle/ventricular
MTEE = matrix-array transesophageal echocardiography
MV = mitral valve
TEE = transesophageal echocardiography
TV = tricuspid valve

The visualization of all MV scallops, IAS, LAA, and LV endocardium was excellent in the majority of patients, as evidenced by scores ranging from 1.74 to 1.91. The presence of atrial fibrillation affected the visualization scores of the LV endocardium, the only structure that required full-volume acquisition. In contrast, visualization quality scores for the AV and TV were lower, between 0.75 and 1.06. The percentage of patients in whom each cardiac structure was assigned an optimal 3D visualization score of 2 was 85% to 91% of all scallops for both MV leaflets, 84% of the IAS, 86% of the LAAs, and 77% of the LV endocardium. In contrast, optimal visualization of the AV cusps was possible only in 18% to 22% of the patients from both the aorta (Figs. 1C and 1D) and the LV perspectives, and in 11% of the TV leaflets from both right atrial (Fig. 2D) and ventricular perspectives. Both the visualization scores and percentages of optimal visualization were similar between institutions.

Discussion

During the last several decades, advances in echocardiography have significantly contributed to its utility as an invaluable diagnostic tool for monitoring of cardiac performance. Transesophageal echocardiography provides clinicians superior image quality and resolution as the result of its immediate proximity between the transducer and posterior cardiac structures, coupled with the absence of lung and bone tissue interference. Three-dimensional echocardiography provides unique visualization and better understanding of the relationship between cardiac structures than 2-dimensional imaging, as well as accurate measurements of valvular and ventricular function (9). Although transthoracic 3D imaging is currently performed in real time with the use of matrix-array transducers, transesophageal 3D imaging with the use of sequential multiplane acquisition has never been embraced in clinical practice. Recent advances in ultrasound transducer technology have simplified the connection between the transducer and the imaging system, resulting in a reduced size of the connecting cable and significantly lowering power consumption, thus allowing real-time 3D TEE imaging.

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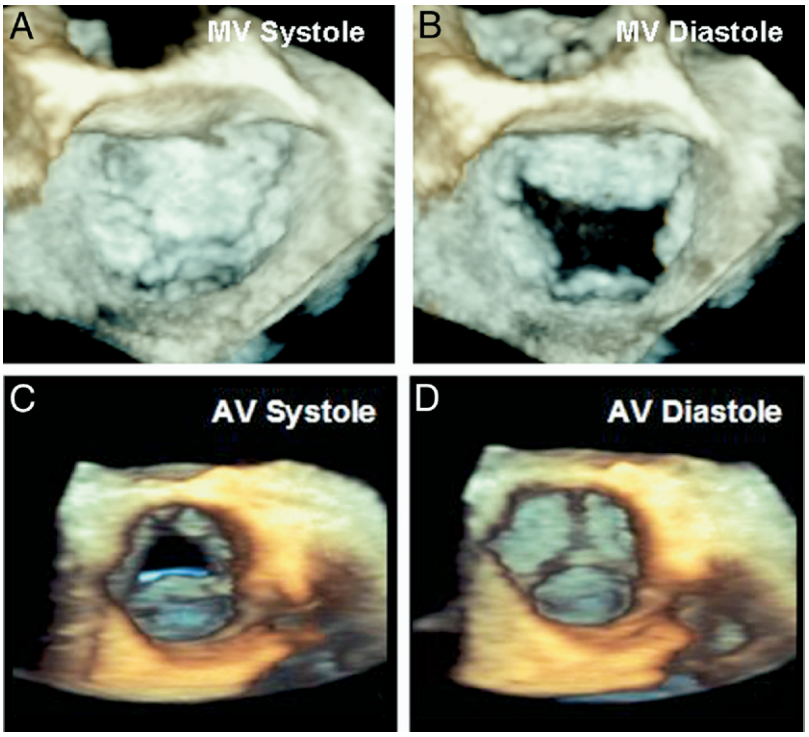

Figure 1 **Volume-Rendered 3D-MTEE Views of Mitral and Aortic Valves**

Example of systolic **(left)** and diastolic **(right)** still frames of 3D-MTEE real-time volume renderings of the MV from the left atrial perspective **(A and B)** and the aortic valves **(C and D)** from the ascending aorta. AV = atrioventricular valve; MV = mitral valve; 3D-MTEE = 3-dimensional matrix array transesophageal echocardiography.

This study is the first to describe the feasibility and clinical utility of real-time 3D-MTEE imaging as reflected by the combined experience of 2 different institutions in a large group of patients. The high success rate of esophageal intubations with the 3D-MTEE probe is not surprising, considering that the size of the probe tip is similar to the existing TEE probe (Omni III). The 3D-MTEE transducer generally provided superb 3D visualization quality of posterior cardiovascular structures and helped identify unique spatial relationships between structures that were not previously observed with either currently available real-time transthoracic or reconstructed 3D TEE imaging technology (Figs. 1 and 2).

One of the major findings of this study was that real-time 3D-MTEE consistently provided excellent quality volume-rendered images of MV components, including anterior and posterior leaflets, as well as annulus and subvalvular structures, as evidenced by the high visualization scores. This finding suggests that 3D-MTEE imaging may become one of the modalities of choice to assess this valve during perioperative planning of MV surgery.

The IAS and LAA were also well visualized because both structures are relatively posteriorly located. The fossa ovalis was easily delineated from the left and right atrial perspectives, which could allow improved guidance of percutaneous closure of atrial septal defects and transseptal punctures. When acquiring the LAA, the left upper pulmonary vein was also readily observed. From these volume data sets, dimensions and area of both orifices and length of the LAA in long-axis can be measured, which could be useful in electrophysiology/interventional procedures such as pulmonary vein ablation or LAA device closures. Transesophageal 3D acquisition of the LV resulted in optimal visualization of the endocardium in 77% of patients despite the requirement of 4 cardiac cycles to complete data acquisition.

We found that anterior cardiac structures, such as the AV and TV, were less well visualized because of leaflet dropout artifacts, which can probably be attributed to the longer distance between these structures and the transducer and to the oblique angle of incidence of the beam combined with the thinner leaflets in these valves.

Study limitations. A limitation of 3D-MTEE technology in its current phase of development is that its use slightly prolongs the TEE examination. However, the ability of the 3D-MTEE probe to display simultaneous biplane imaging is likely to shorten the examination time. In the future, 3D examinations will be shortened by using standardized display protocols that will eliminate the need for manual cropping of datasets. Also, we noticed that having 2 operators involved in image acquisition, one manipulating the transducer and the other optimizing imaging settings, can significantly improve image quality.

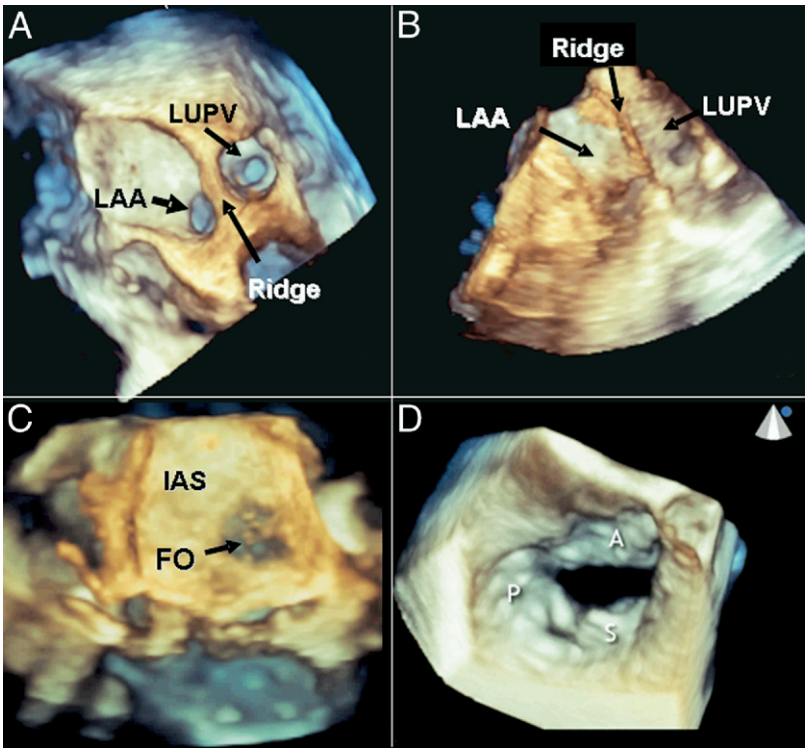

Figure 2 **Volume-Rendered 3D-MTEE Views of Different Cardiac Structures**

Examples of the left atrial appendage (LAA) visualized en-face **(A)** and in the long-axis view **(B)** showing the ridge separating the LAA from left upper pulmonary vein (LUPV); **(C)** interatrial septum (IAS) from the left atrial perspective showing the foramen ovale (FO); **(D)** tricuspid valve displayed from the right atrial perspective showing the septal (S), anterior (A), and posterior (P) leaflets. 3D-MTEE = 3-dimensional matrix array transesophageal echocardiography.

Conclusions

In summary, although the 3D-MTEE probe allows excellent visualization of native MVs, LAA, IAS, and pulmonic veins, consistent optimal imaging of the AV and TVs may require further technological advances. Optimal visualization of MV apparatus components may allow quantification of its complex geometry and thus improve the diagnostic accuracy of echocardiographic evaluation of the MV. Overall, the ease and speed of data acquisition coupled with the ability to display cardiac structures using unique 3D views is likely to result in rapid integration of 3D-MTEE into clinical practice.

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Key Words: transesophageal echocardiography ■ 3-dimensional echocardiography ■ intraoperative echocardiography ■ mitral valve ■ valvular disease.

APPENDIX

For an accompanying video, please see the online version of this article.