Utilization of Real-time 3D Transesophageal Echocardiography in an Urban Academic Medical Center

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ABSTRACT

Purpose: Real-time three-dimensional transesophageal echocardiography (3D TEE) is useful in a variety of clinical scenarios. However, the pattern of its clinical utilization in an urban academic center is unknown. The objective of this study is to evaluate the practical use of 3D TEE and to explore factors that may affect its applications. **Methods:** We conducted a retrospective study by reviewing 2,734 consecutive TEEs performed at Montefiore Medical Center in Bronx, NY, between January 2009 and August 2011. Types of 3D modes (biplane, live, 3D zoom, full volume, and 3D quantifications) and indications were reviewed. Linear regression was performed to examine the association between echocardiographers' characteristics and 3D TEE utilization. **Results:** 3D modalities were utilized in 1,655 studies (61%) during the study period. The use of 3D technology increased from 44% at 4 months to 79% at 32 months. Biplane, 3D zoom, and full volume acquisition showed a steady increase, but quantification remained very low throughout the study period. Level 3 training was significantly associated with 66.6% (95% CI 13.0%, 120.1%, $P = 0.029$) higher rate of 3D TEE utilization compared to level 2, after adjusting for age, sex, years of practice, and total TEE volume. Level 3 echocardiographers utilized more zoom 3D and full volume, whereas level 2 echocardiographers used biplane more frequently. **Conclusions:** There has been a growing use of 3D TEE over time, but not all 3D modes were equally employed. The association between advanced training and increased 3D utilization is likely due to interest and self-motivation.

Keywords: Echocardiographer, echocardiography, real-time three-dimensional transesophageal echocardiography, utilization

INTRODUCTION

Real-time three-dimensional transesophageal echocardiography (3D TEE) uses fully sampled matrix array transducers, allowing for real-time imaging. It has provided unique views of cardiac structures that were previously unseen by echocardiographers. It has undoubtedly improved communication between surgeons, cardiologists and anesthesiologists when discussing complicated cardiac structural abnormalities.

Compared to 2D, real-time 3D TEE offers a spectrum of advantages, including live imaging and direct visualization of cardiac structures. It provides a more complete spatial orientation, which is useful for localizing ventricular septal defects, the atrial septal rim, and measuring the size of atrial septal defects. These are particularly important when percutaneous device closure is being considered. There had been numerous publications demonstrating the improved accuracy and reproducibility over 2D technology for certain clinical applications, such as the left ventricle (LV) volume quantification, intracardiac thrombosis and mitral valve.[1-6] In accordance with the growing literatures, American Society of Echocardiography and European Association of Echocardiography have recommended 3D TEE as a complement to routine 2D echocardiography in daily clinical practice and published various indications of utilizing 3D TEE in the assessment of cardiac function and structure.[7]

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There are different types of acquisition modes of 3D TEE (Table 1).[8,9] A biplane mode can be used to obtain views from two different angles simultaneously. Zoom mode is a live mode requiring no gating, which displays a manually adjusted truncated pyramidal volume. Full volume can generate wide scanning volumes and still maintain high temporal and spatial resolution. The full volume images can be cropped and process for chamber quantifications and volumetric quantitative analysis of valves.

Real-time 3D TEE technologies have been commercially available since 2007. There have been a few studies examining the interpretation and analysis of 3D TEE results,[10-12] but the pattern of its clinical utilization in an urban academic center is not known. Therefore, we conduct the current study to evaluate utilization of 3D TEE technology and to explore factors that may affect its applications. The results of this study may have important implications for the training and education of non-invasive cardiologists.

METHODS

We performed a retrospective study by reviewing 2,734 consecutive TEEs at Montefiore Medical Center in Bronx, NY between January 2009 and August 2011. Montefiore Medical Center is a 1,491-bed general medical and surgical facility with 85,556 admissions in the most recent year. The hospital has around 12,721 Medicare inpatients with cardiac conditions between 2008 and 2010. Images were acquired using the iE33 ultrasound system equipped with a 3D matrix array TEEs transducer (Philips Medical Systems, Andover, Massachusetts). Offline analysis was performed with the Xcelera program and QLAB software (Phillips Healthcare, Andover, MA). Real-time 3D TEE probes became available at our medical center at the end of December 2008. Active use of 3D TEE imaging began within a month of its availability. The same group of staff attending echocardiographers learned real time 3D TEE during daily clinical practice. They all attended the initial formal training courses sponsored by Philips Medical Systems. Philips application specialists were also invited to come on site for knobology training a few months after the initial course to provide learning reinforcement. Sonographers were not involved in the study. Of note, level 2 training involves 6 months of echocardiography, with 150 studies performed and 300 interpreted. In comparison, level 3 certification requires 12 months of echocardiography training, with 300 studies performed and 750 interpreted.

Table 1 Three-dimensional (3D) imaging modes

Modes	Biplane	Zoom	Full volume
Dimensions	Any two 2D cut planes	20°×20° to 90°×90° by a variable height	90°×90° by the depth of the 2D image
Frame rate	30-60 Hz	5-10 Hz	20-40 Hz (4 beats)
Temporal resolution	Good	Lowest	40-50 Hz (7 beats)
Spatial resolution	Moderate	Highest	Lowest
Cardiac structure	Any 2D image	Cardiac valves, interatrial septum, left atrial appendage	Mitral valve, left ventricle
Clinical application	Exam cardiac anatomy from different views simultaneously	Examine anatomy	Left ventricular function color Doppler

We summarized the number 3D TEE performed and graphically illustrated the change of utilization over time. The types of 3D modes (biplane, 3D zoom, full volume and 3D quantifications) and indications for TEE exams were reviewed. Full volume images were counted regardless of post-processing.

Statistical analysis

Stata 11 (StataCorp LP, College Station, Texas, USA) was used for data analyses. We examined the characteristics of levels 2 and 3 echocardiographers, including age, gender, number of years of practice, 3D TEE volume, and total TEE volume. For each echocardiographer, the use of 3D TEE was quantified using the percentage of 3D TEE volume over the total TEE volume. *T*-test and Pearson's Chi-squared test were performed to assess if the characteristics were different between the level 2 and level 3 echocardiographers. Unadjusted and multivariate adjusted linear regressions were performed to detect the association between echocardiographers' characteristics and the utilization of 3D, percentage of 3D TEE volume over the total TEE volume. In the multivariate linear logistic regressions, the adjusted covariates included gender, age, years of practice, and total TEE volume.

RESULTS

Among the 2,734 TEEs examined, 3D imaging modalities were utilized in 1,655 studies (61%) during the study period, from January 2009 to August 2011. There was a growing trend in the use of 3D technology over the 32-month period (Figure 1). By 20 months, 3D was consistently employed in more than half of all TEE studies. Further analysis indicated that not all 3D modalities were equally employed (Figure 2). Specifically, biplane, 3D zoom, and full volume acquisition showed a steady increase in utilization over the study period.

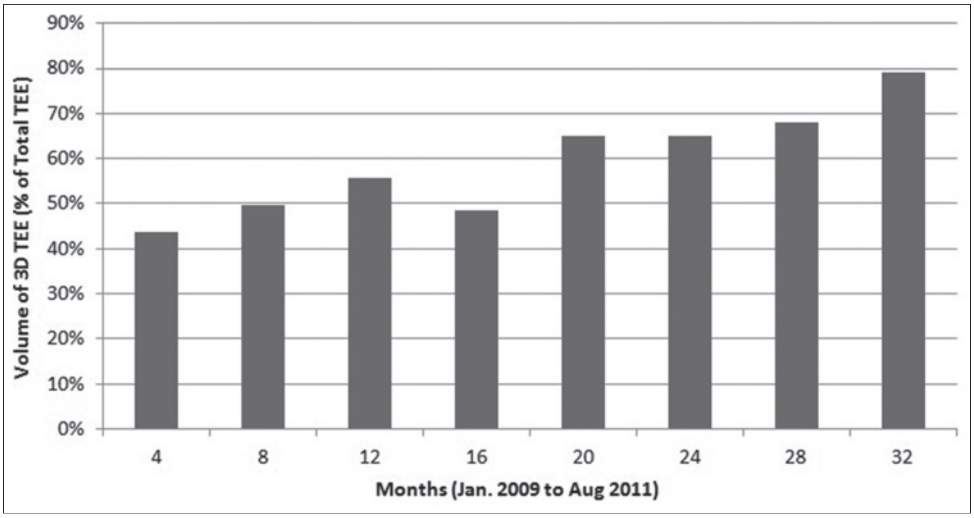

Figure 1. Trend of three-dimensional transesophageal echocardiography utilization.

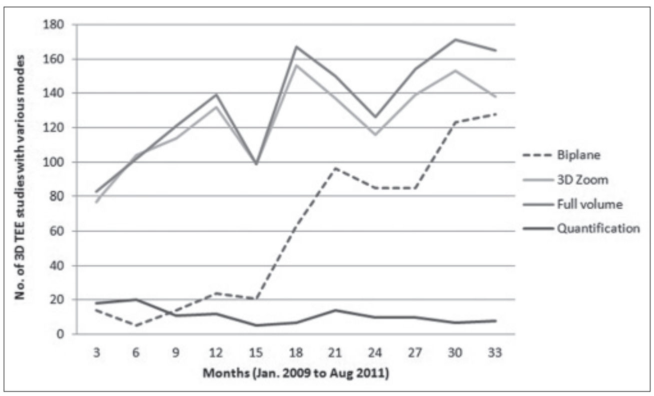

Figure 2. Utilization of various types of three-dimensional modes.

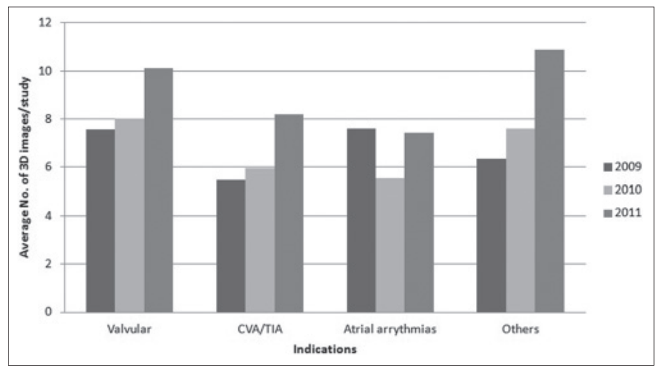

Figure 3. Trend of three-dimensional images acquired by indications.

The increase in use of the biplane method was especially striking, from only 14 studies at 3 months to 128 at study end. The number of studies with quantification remained very low (≤20) throughout the study period. These studies were mainly from mitral value quantification and LV volume probably represented 10% of total quantification acquisition.

We also examined the trend of 3D utilization among all TEEs in the study period by indications (Figure 3). There was an increase in the use of 3D techniques in studies performed for valvular heart disease, cerebrovascular accident/transient ischemic attack, and miscellaneous. The use of 3D in atrial arrhythmias did not increase over the study period. The miscellaneous group included indications such as intracardiac thrombus and shunts, as well as arterial embolization and aortic aneurysm/dissection, which were among the most prevalent indications in this group.

At our center, there were a total of five level 2-trained echocardiographers and four that were level 3. Among all TEEs performed in the study period, on average, 82% of 3D TEEs were performed by level 3 echocardiographers, compared to 18% by level 2. The utilization of 3D TEE by levels and by year is shown in Figure 4. In 2009 and 2010, the utilization of 3D TEE was significantly higher in level 3 compared to level 2 echocardiographers (in 2009, 68% vs. 15%, $P = 0.004$; in 2010, 78% vs. 30%, $P = 0.003$). In 2011, level 3 echocardiographers still utilized more 3D TEEs, but not significantly higher than level 2 (84% vs. 58%, $P = 0.26$). There was no significant difference in the change of 3D TEE utilization over time between levels 2 and 3 echocardiographers (2009 vs. 2010, $P = 0.60$; 2010 vs. 2011, $P = 0.16$). The number of 3D TEE images acquired by level 2 versus level 3 echocardiographers is shown in Figure 5. The images per study increased over time and on average, level 3 acquired more images per study (mean = 8.5) compared to level 2 (mean = 4.5).

The characteristics of levels 2 and 3 echocardiographers are shown in Table 2. The mean age of level 2 was 39.6 versus 41.8 years for level 3. The average number of years of practice among level 3 echocardiographers was twice that

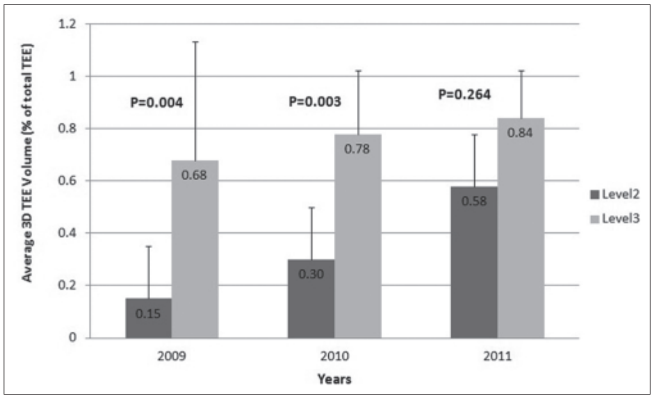

Figure 4. Three-dimensional transesophageal echocardiography utilization of level 2 vs. level 3 echocardiographers, by year.

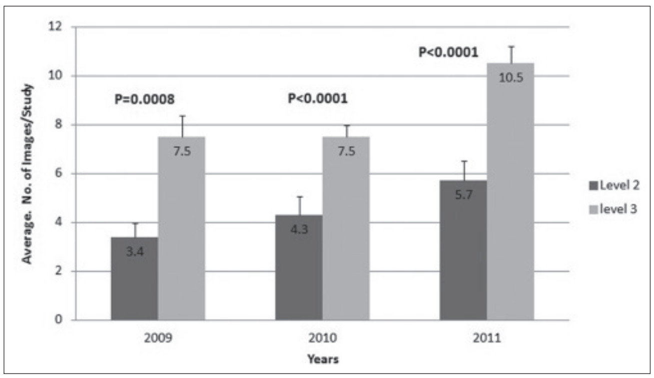

Figure 5. Numbers of three-dimensional transesophageal echocardiography images per study by level 2 vs. level 3 echocardiographers, by year.

of level 2, but was not statistically significant (P = 0.18). The mean total TEE volume was much higher for level 3 compared to level 2, but it was not significant (455.8 vs. 189.4, P = 0.09). The average number of 3D TEE performed by level 3 echocardiographers was significantly greater than level 2 (338 vs. 65, P = 0.02). The average percentage of 3D TEE performed was also significantly higher in level 3 compared to level 2 (78.7% vs. 39.4%, P = 0.03).

In univariate linear regressions, none of the echocardiographers' characteristics (age, sex, years of practice and total TEE volume) was associated with 3D TEE utilization, except for advanced training (beta = 39.3%, 95%CI 5.3%, 73.3%, P = 0.029). In the multivariate linear regression, advanced training (being level 3) was significantly associated with a 66.6% (95% CI 13.0%, 120.1%, P = 0.029) higher rate of 3D TEE utilization, after adjusting for age, gender, years of practice, and total TEE volume. The difference in percentage of studies with various 3D TEE modes between levels 2 and 3 echocardiographers is presented in Table 3. Zoom 3D and full volume were significantly more frequently utilized by level 3 compared to level 2 echocardiographers. However,

Table 2 Characteristics of levels 2 and 3 echocardiographers

	Echocardiographers						*P* value
	Level 2 (*n*=5)			Level 3 (*n*=4)			
	Mean	SD	%	Mean	SD	%	
Age (year)	39.6	2.4		41.8	2.7		0.57
Female (%)			20			25	0.86
Years of practice	4.4	1.4		8.5	2.6		0.18
Total TEE volume	189.4	54.0		455.8	135.6		0.09
3D TEE volume	65	17.5		338	98.8		0.02
Percentage of 3D TEE performed			39.4			78.7	0.03

3D TEE: Three-dimensional transesophageal echocardiography, SD: Standard deviation

Table 3 Comparison of different 3D TEE modes between levels 2 and 3 echocardiographers

	Echocardiographers		*P* value
	Level 2	Level 3	
Percentage* of studies with biplane	49.9	36.7	<0.001
Percentage* of studies with zoom 3D	51.7	88.5	<0.001
Percentage* of studies with full volume	67.1	93.1	<0.001
Percentage* of studies with quantification	4.6	7.9	0.04

*Percentage=Numbers of 3DTEE with certain type of images/total number of 3D TEE performed by level 2 or 3 echocardiographers. 3D TEE: Three-dimensional transesophageal echocardiography

level 2 echocardiographers tended to use biplane more frequently than level 3 echocardiographers.

DISCUSSION

The current study explores the practical use of 3D TEE in a large urban hospital. We found a tremendous and growing enthusiasm, from only 44% of TEE studies with 3D images near the beginning, to almost 80% at the end of this 32-month study. This increasing trend may persist as real-time 3D technology continues to improve diagnostic accuracies, both in and outside of the operating room.

In addition, advanced training (level 3 echocardiographers) is significantly associated with improved utilization of 3D TEE, compared to level 2. Note that all echocardiographers involved in the study completed their echocardiography training prior to the advent of commercially available real-time 3D TEE in 2007. Thus, most of the 3D TEE learning occurred during daily clinical practice. However, a few strategies were implemented to encourage its applications. For instance, all imaging faculty attended the initial formal training courses sponsored by Philips Medical Systems. Philips application specialists were also invited to come on site for knobology training a few months after the initial course to provide learning reinforcement.

Since 2007, many studies have supported the use of live 3D TEE as a crucial supplement to 2D, particularly in the examination of mitral valve disease and intracardiac shunts. Biaggi *et al*. showed that measurements of mitral valve anatomy on real-time 3D TEE were accurate compared to surgical measurements.[5] In another study, 3D technology more accurately determined the location of mitral valve prolapse compared to 2D, and it has been widely accepted to be an integral part of the pre-operative examination prior to mitral valve repair.[6] In accordance with the growing literature citing its advantages, we showed that there was an increase in the use of 3D TEE for various indications, including valvular heart disease and stroke or transient ischemic attack.

An interesting difference in the use of specific 3D modes was seen in regards to quantification. The number of studies with quantification remained very low (≤20) throughout the study period, which were mainly from mitral value quantification. One explanation for this phenomenon is the tedious processing associated with quantification, particularly for mitral valve quantification. Thus, 3D quantification was overall underutilized likely due to its time-consuming nature and clinical demand for the physician's productivity.

A significant difference in the employment of 3D TEEs between levels 2 and 3-trained echocardiographers was observed. Throughout this study, level 3 echocardiographers performed the majority of TEEs with 3D images. There was a small increase in number of 3D TEEs performed by level 2 physicians, from 12% in 2009 to 58% in 2011. The increased volume of 3D imaging over the study period was secondary to improved learning by level 2 echocardiographers rather than higher number of studies performed by level 3. The overall discrepancy in the use of 3D between the different levels of training is likely due to interest, comfort level and higher total TEE volume in level 3 echocardiographers. Thus, advance training appears to increase the utilization of 3D TEE.

There have not been any large-scale, randomized control studies to examine whether the use of 3D TEE improves outcomes. However, numerous studies have suggested that the improved diagnostic accuracies of 3D TEE, particularly in guiding specific interventions, may eventually translate into benefits in morbidity and mortality. The role of 3D TEE in the assessment of mitral valve pathologies, cardiac diseases such as hypertrophic cardiomyopathy, complex congenital heart disease, and guidance of catheter-based interventions have been validated by numerous studies.[13-16] Although there has not been any clear evidence that 3D TEE directly led to survival benefits or reduction in complications or readmission rates, it is clear that this technology had facilitated the works of surgeons, anesthesiologists, and cardiologists in ways that 2D TEE is unable to offer.

Recent studies have shown that LV volume and functional measurements by 3D technology are more reproducible and more closely agree with those by cardiac magnetic resonance imaging compared to 2D.[17,18] Single-heartbeat full volume acquisition with high temporal and spatial resolution has been showed superior to four-beat electrocardiograph-gated acquisition in patient with atrial fibrillation.[19] The utilization and efficiency of 3D TEE will likely be enhanced once the technology advances, such as real-time 3D color Doppler imaging with a larger angle, can be done. As strides are made in 3D technology, it is likely that real-time 3D TEE will become an increasingly important tool in clinical cardiology.

Bolling *et al*. had shown that the probability of mitral valve repair versus replacement increases with not only certain patient characteristics, but also surgeon repair volumes.[20] From this, they concluded that perhaps a certain minimal number of cases/year must be achieved for one to be considered a reference mitral valve surgeon. A similar approach with the performance of 3D TEE should be considered to enhance the educational experience in non-invasive cardiology. As 3D TEE becomes an integral part of cardiac imaging that guides surgical decisions and other therapies, mandatory training and certification may be required in the near future for all non-invasive cardiologists.

Limitations

The limitations of this study include its retrospective, single-center nature, and the relatively small number of echocardiographers. In addition, there may be other difficult-to-measure factors besides the studied characteristics that may influence the echocardiographers' decision to use 3D. Further studies involving multiple institutions are warranted to fully explore the factors that influence the use of this increasingly important technique.

CONCLUSION

This study describes the trend of 3D TEE use by echocardiographers in an urban academic setting. There has been a growing use of 3D TEE technology for the evaluation of various cardiovascular disease processes, but not all 3D modes were equally employed. The only characteristic that correlated with the use of 3D technology was advanced training in echocardiography. The results of this study may have important implications for the training and education of this increasingly important technology.

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