NOVEL APPROACHES TO TRAINING IN CV ULTRASOUND

Effects of Transesophageal Echocardiography Simulator Training on Learning and Performance in Cardiovascular Medicine Fellows

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Background: The role of transesophageal echocardiography (TEE) simulation in cardiology fellows’ learning is unknown. Standard TEE training at the authors’ institution occurs during the second of 3 clinical years. Fellows spend 2 months in the TEE laboratory learning through hands-on experience. The addition of TEE simulation to this experience may improve proficiency, speed learning, and increase fellows’ comfort with TEE. This study was designed to compare methods of TEE simulator training with standard training.

Methods: Group A (n = 8) consisted of fellows who had completed standard TEE training. Fellows starting their second clinical year were randomly assigned to group B (n = 10), simulator training during month 1, or group C (n = 9), simulator training during month 2. All groups completed 2 months of standard TEE training. All groups underwent assessment of TEE performance and a self-assessment of ability and comfort level with TEE.

Results: Groups B and C had higher total assessment scores than group A. Groups B and C had higher numbers of views achieved without assistance (P = .01). After month 1, group B had higher total scores and number of views achieved without assistance compared with group C (P = .02 and P = .02, respectively). The length of time of the examination tended to be lower for group B, and fellows in group B had greater comfort with TEE than those in group C (P = .01).

Conclusions: These data suggest that TEE simulator training improves proficiency and helps speed learning and comfort with TEE. (J Am Soc Echocardiogr 2013;26;1450-6.)

Keywords: Transesophageal echocardiography, Simulation

Simulation-based training has emerged as a valuable tool in the medical field for the development and assessment of technical skills and knowledge among trainees. Initially developed for the training of pilots and military personnel, simulation is increasingly being used by residency and fellowship programs in areas such as surgery, anesthesiology, emergency medicine, and cardiology.1-7 Trainees in these procedural specialties have traditionally acquired the requisite technical skills by performing procedures on patients under the supervision of experienced physicians. Simulation-based training enables these trainees to develop and practice their skills before applying these techniques in a patient setting. In cardiovascular medicine, simulation training has been developed for coronary angiography, electrophysiologic applications such as transseptal catheterization, and echocardiography.8-22 Procedural competency in transesophageal echocardiography (TEE) is a required component of our cardiovascular medicine fellowship training. Our observation has been that the learning curve for the acquisition of technical expertise varies substantially among fellows, and a method of speeding and standardizing this process would be beneficial.

The role of TEE simulation in cardiovascular medicine trainees’ learning and performance is unknown. We hypothesized that TEE simulator training among cardiovascular medicine fellows is superior to standard training and will improve proficiency in the performance of TEE, speed learning, and increase trainee comfort with the procedure.

METHODS

TEE Simulator

The HeartWorks TEE simulator (Inventive Medical, Ltd., London, UK) was used in this study (Figure 1). The simulator consists of a manikin upper-body torso with a transesophageal echocardiographic probe inserted into the mouth of the manikin; the probe is connected to a dedicated computer with proprietary software. The probe has authentic controls with standard flexion, rotation, and angulation capabilities of a clinical multiplane probe. As the cardiovascular medicine fellow performs an examination, a simulated ultrasound image of the heart is generated on one part of the screen with a three-dimensional virtual heart adjacent to it. The three-dimensional heart model can be manipulated to display "slices" through the heart.
that correspond to the accompanying ultrasound-generated images. The simultaneous viewing of the two-dimensional ultrasound image and the threedimensional anatomy of the heart promotes development of the requisite spatial-anatomic knowledge for transesophageal echocardiographic examinations.

**Study Design**

The study was approved by the institutional review board at Vanderbilt University Medical Center. Participation was voluntary, and all eligible cardiovascular medicine fellows provided consent to participate in the study. The study flowchart is shown in Figure 2. The standard TEE training at our institution occurs during the second of 3 clinical years. During this year, the fellows rotate through the TEE laboratory for 2 months, learning the procedure through direct hands-on experience. Group A was composed of fellows who were completing the second year of clinical training and had completed our standard TEE curriculum (n = 8). This group completed this training before our access to the TEE simulator and served as historical controls. Upon completion of standard TEE training, fellows in group A underwent a one-time assessment of their performance by conducting a comprehensive transesophageal echocardiographic examination on an actual patient as described below.

Cardiovascular medicine fellows who were beginning their second clinical year and had no prior formal TEE instruction were randomized into two groups, group B (n = 10) and group C (n = 9). These trainees completed our standard TEE training program but also had an opportunity to train with the TEE simulator during 1 of their 2 rotation months. At the beginning of their first TEE rotation month, group B received instruction on the use of the TEE simulator by an attending physician. Fellows in group B were expected to practice their procedural skills using the simulator for ≥2 hours per week in addition to their clinical duties of performing TEE on scheduled inpatients and outpatients. During their second TEE rotation month, fellows in group B performed their usual clinical duties and standard training. Group C completed standard TEE training during their first rotation month. They were then instructed on the TEE simulator and asked to use this tool for training during their second rotation month.

At the conclusion of each of their two rotation months, fellows in groups B and C underwent a formal assessment of their ability to perform a complete transesophageal echocardiographic examination on an actual patient and also completed a self-assessment questionnaire. The performance evaluation (Appendix A) and the self-assessment questionnaire (Appendix B) were the same across groups A, B, and C.

The transesophageal echocardiographic examination consisted of 37 views or structures and awarded 2, 1, or 0 points for each view obtained without instruction, obtained with instruction, or not obtained, respectively. The maximum score achievable was 74 points (Figure 3). Fellows were allowed to perform the transesophageal echocardiographic examinations in their preferred sequences. If they attempted and were unable to achieve a view, verbal instruction was given. If achieved, this was deemed to be “achieved with instruction.” If the view could still not be obtained, this was deemed to be “not achieved.” If at the completion of the study, a view had not been attempted (not included in the fellow’s complete study), the fellow was asked to obtain the view, and this was deemed to be “not achieved.” Doppler assessment was required for the view to be deemed “achieved” for structures in which this assessment would be considered part of a complete evaluation (i.e., color Doppler of the mitral valve). The time to completion of the entire examination was recorded by the attending physician supervising the study. The skills assessments were performed by the same two faculty members to increase the consistency of the examinations, and the format of the examination as described above was followed for each assessment. The assessments were performed on patients referred for TEE, who provided a high probability of being able to complete a full examination. Because of logistic constraints, the faculty was not blinded as to use of the simulator. Fellows also completed a self-assessment questionnaire rating their ability and comfort levels with the procedure. The self-assessment questionnaire was graded on a scale of 1 to 5 and included questions regarding confidence level with the performance and interpretation of the examination (5 being most confident) and the utility of simulator training (5 being most useful).

The primary end points of our study were the difference in total and view-specific transesophageal echocardiographic examination scores between fellows who completed our standard training (group A) and simulator-based training (groups B and C) and the difference in total and view-specific examination scores between groups B and C after TEE-based simulator training during the first month versus the second month of their clinical training.

**Statistical Analysis**

We compared TEE simulator view assessment scores as the outcomes. Categorical variables are expressed as percentages. Wilcoxon’s tests were used for comparison of continuous variables among groups; all results are expressed as median scores. P values < .05 were considered statistically significant. All statistical analysis was conducted using R version 2.13.1 (R Foundation for Statistical Computing, Vienna, Austria).

**RESULTS**

After completing TEE training, groups B and C (those with simulator training) had higher total assessment scores than group A (those without simulator training) (median, 72 vs 68.5; Figure 4A). Groups B and C also had higher numbers of views achieved without assistance and lower numbers of views that were not achieved (median, 35 vs 33 [P = .01] and 0 vs 2 [P = .03], respectively; Figure 4B). There was a significant difference in score for groups B and C for deep esophageal views as well as transgastric views compared with group A (median, 6 vs 5.5 [P = .02] and 13 vs 9.5 [P = .04], respectively; Figure 4B). There was no significant difference in scores for midesophageal or aortic views. There was also no significant difference between the fellows’ perceptions of the TEE training, comfort with performing TEE, or perception of ability to perform or interpret the results of TEE. Although not statistically significant, the mean time for completion of TEE tended to be lower for groups B and C (15.9 min) compared with group A (17 min).

When groups B and C were compared, group B had higher total scores after month 1 compared with group C (P = .02), which may have been due to higher midesophageal and gastric view scores (P = .01 and P = .02, respectively) (Figure 5A). The number of views achieved without assistance was different (P = .02), and the number of views achieved with instruction was lower for group B compared with group C (P = .01) (Figure 5B). The length of time of the examination also tended to be lower for group B. In addition, group B trainees, who had been exposed to simulator-based training during their first month, were able to maintain their skill set from month 1 to month 2, as measured by a smaller change in total score compared with group C (Figure 6). Fellows in group B appeared to have greater...
comfort with TEE and with the interpretation of normal transesophageal echocardiographic results than those in group C ($P = .01$ and $P = .01$, respectively). Although not statistically significant, group B tended to have greater comfort with interpretation of abnormal transesophageal echocardiographic results and more confidence in their ability to perform TEE.

The amount of time actually spent on the simulator was self-reported and averaged 1 hour per week, with a range of 0.25 to 2 hours per week. The mean number of transesophageal echocardiographic studies performed did not vary significantly among groups (group A, 92; group B, 104; and group C, 86). No relationship was found between assessment scores and prior physics education, interest in a career in imaging, number of months between TEE rotation months, or number of months spent on transthoracic echocardiography training.

**DISCUSSION**

Becoming proficient in TEE requires learning a complex set of skills that include knowledge of normal cardiac anatomy, ease with manipulation of the transesophageal echocardiographic probe, and...
accuracy in obtaining multiple, complex TEE views, in addition to assessment of the patient’s response to and comfort during the examination. TEE simulator–based training is a promising new method of teaching this imaging modality to cardiovascular fellows and provides learners with a low-risk, low-pressure environment from which the time constraints and anxiety of patient care are removed. It also allows trainees time to break down this complex modality into small steps, practicing views they find technically or visually challenging.

TEE simulation training has been shown to improve knowledge of anatomy and image interpretation compared with the use of standard learning resources such as textbooks and Web-based media. To our knowledge, this is the first study to assess skill acquisition with a TEE simulator compared with traditional “hands-on” training alone. In this study, we found that the incorporation of TEE-based simulator training into our standard curriculum improved scores on a TEE skills assessment test performed on actual patients in the clinical setting. This was most notable for the deep esophageal and transgastric views, in which understanding probe position relative to cardiac anatomy may be more challenging than for the midesophageal and aortic views. In addition, this training increased the speed of learning and provided the fellows with a durable skill set that was maintained over the course of 1 year of cardiology training. Although not statistically significant, there was a trend toward shorter total transesophageal echocardiographic examination times with use of this teaching method. Fellows exposed to the simulator in month 1 of their training tended to have improved confidence in their ability to perform and interpret TEE at this early stage of training compared with those fellows not yet exposed to the simulator.

This was a single-institution experience with a relatively small sample size, and as such, our protocol and findings may not be easily adaptable or generalizable to other training programs in which TEE training is structured differently. On the basis of self-reported time spent on the simulator, use varied among fellows and averaged 1 hour per week. We would suspect that use varied on the basis of several factors, including motivation of the fellow as well as skill and comfort level with TEE. Investigation into motivational factors and barriers to use for fellows might identify factors that can increase the use of this type of resource when available. The relatively small differences in assessment scores along with the small sample size of our study did not allow correlation of the time spent on the simulator with scores. This raises the question of whether there is a minimum amount of time needed on the simulator before a significant improvement in TEE skills can be achieved. Future study to identify the ideal ratio of time spent on the simulator to benefit in skills is warranted. Because of logistics and time constraints of supervising faculty members, the fellows did not receive direct feedback while using the simulator. This required the fellows to take feedback given during actual cases and apply it to their independent learning with the simulator. A strategy allowing immediate feedback while on the simulator might further enhance or speed learning.

The use of such a procedural simulator can potentially generate an overly controlled environment that does not develop skills that are translatable to the patient care realm. Given the technical nature of the skills that this simulator curriculum was targeting, the concern that this would not be applicable in the clinical setting is smaller, and our assessments were performed in the clinical setting. Our findings support the hypothesis that training with the TEE simulator may be useful in assisting with the psychomotor skills required to perform TEE and may speed the learning of normal views and cardiac anatomy. However, there are several aspects of TEE training that we would not expect this type of simulator to be able to recreate. The simulator used in this study was able to demonstrate only normal anatomy and therefore not able to aid in the interpretation of
pathology or Doppler assessment. The simulator was not able to recreate the respiratory and hemodynamic changes that can occur during conscious sedation for TEE, to adjust for the individual complexities of patients, or to account for potential complications which may occur. Knowing how to handle these aspects of TEE is essential to being competent in the procedure, and these are skills which cannot be taught with the simulator training described here. Therefore, the TEE simulator should be viewed as a tool that complements, rather than replaces, traditional training with experienced supervising faculty members. As higher fidelity simulators that have the ability to simulate pathology, patient characteristics, and complications become available, additional studies will be needed to understand the effect of these tools on learning to perform and interpret TEE.

The cost of providing trainees with access to a TEE simulator must be weighed with the potential benefits. Similar to other types of sophisticated simulator technology, the initial purchase price of the TEE simulator is high (approximately $60,000; http://www.heartworks.me.uk). In addition to the purchasing price, the simulator may have costs associated with maintenance, software updates, and housing (the simulator we used requires at least a 20 ft² space for housing and use). Costs that are more difficult to quantify but equally important when considering incorporating this technology into the

Figure 4. Comparison of total examination scores between group A and groups B and C at the completion of training (A). Comparison of views achieved with assistance, views not achieved, and examination scores for standard transesophageal echocardiographic views between group A and groups B and C at the completion of training (B).
Figure 5 Comparison of scores in each of three standard transesophageal echocardiographic views between groups B and C after month 1 of training (A) and total scores and number of views achieved with and without assistance between groups B and C after month 1 of training (B).
trainees’ curriculum include the time required for faculty members to learn and teach the technology. Given these factors, supplementation of traditional training may also be done with online resources, which may require less investment of money and faculty time. An online model of TEE that recreates standard views and allows comparison with three-dimensional orientation on a heart model has been shown to improve knowledge of navigation among 20 standard transesophageal echocardiographic views. Pairing of this type of learning to improve knowledge of navigation among 20 standard transesophageal echocardiographic views and help speed learning and comfort with this modality.

CONCLUSIONS

The addition of a TEE simulator to our traditional TEE training was favorably received by our cardiology fellows. Our study suggests that simulator training may improve proficiency in performing TEE and help speed learning and comfort with this modality.

REFERENCES

**Skills Assessment Checklist for TEE Simulator**

**Assessment**

Instructions: Please observe a complete TEE performed by the fellow and check the appropriate box for each structure.

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<thead>
<tr>
<th>View</th>
<th>Achieved</th>
<th>Achieved with Instruction</th>
<th>Not Achieved</th>
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<tbody>
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<td>Mid esophageal</td>
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<td>LV apical 4 chamber</td>
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<td>LV apical 2 chamber</td>
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<td>LV apical long axis</td>
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<td>RV apical 4 chamber</td>
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<td>Mitral valve 0 degrees (with color Doppler)</td>
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<td>Mitral valve 45 degrees (with color Doppler)</td>
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<td>Mitral valve 75 degrees (with color Doppler)</td>
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<td>Mitral valve 105 degrees (with color Doppler)</td>
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<td>Mitral valve 130 degrees (with color Doppler)</td>
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<td>LA appendage from 0 to 180 degrees (with PW Doppler)</td>
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<td>Left upper pulmonary vein (with PW Doppler)</td>
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<td>Right upper pulmonary vein (with PW Doppler)</td>
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<td>Right lower pulmonary vein (with PW Doppler)</td>
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<td>Aortic valve short axis (with color Doppler)</td>
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<td>Aortic valve long axis (with color Doppler)</td>
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<td>Ascending aorta</td>
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<td>Pulmonary artery</td>
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<td>Pulmonic valve (with color Doppler)</td>
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<td>Tricuspid valve 0 degrees (with color Doppler)</td>
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<td>Tricuspid valve 45 degrees (with color Doppler)</td>
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<td>Interatrial septum 45 degrees (with color Doppler)</td>
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<td>Interatrial septum in bicaval view (with color Doppler)</td>
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<td>Agitated saline injection with imaging of interatrial septum</td>
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<td>Deep esophageal</td>
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<td>RV</td>
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<td>Tricuspid valve</td>
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<td>Coronary sinus</td>
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<td>Transgastric</td>
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<td>LV short axis at mitral valve</td>
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<td>LV short axis at papillary muscles</td>
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<td>LV short axis at apex</td>
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<td>LV long axis at 90 degrees</td>
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<td>Tricuspid valve/RV inflow at 90 degrees</td>
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<td>Pulmonary valve</td>
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<td>Aortic valve deep transgastric</td>
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<td>Aorta on probe withdrawal</td>
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Scoring system: Achieved = 2 points, Achieved with Instruction = 1 point, Not Achieved = 0 points

Total Score: __________

Total Score: __________

Time of exam start: __________ Time of exam completion: __________ Total time of exam (minutes) __________
APPENDIX B

Questionnaire for TEE Simulator Training

Name: _______________________________________

Instructions: Please answer these questions to the best of your knowledge. This information is being used for educational and research purposes only and will not be attached to your echocardiography training information.

1. What is your current PGY year? 4 5 6 7 8
2. Do you have an educational background in physics? Yes No
3. Did you have formal TEE training prior to beginning your fellowship? Yes No
4. Are you planning on specializing in imaging? Yes No
5. How many months in the last 12 months have you spent on a TEE rotation? _____
6. How many weeks during this TEE time were you on vacation? _____
7. How many months were between your TEE months if there were more than one? _____
8. How many months during your fellowship have you spent on a transthoracic echo rotation? _____
9. How many TEEs have you performed? _____
10. How many TEEs did you perform during your first year of fellowship? _____
11. How many TEEs have you performed at rotations outside of the TEE rotation (VA, Meharry)? _____
12. How many hours a week on your TEE rotations did you spend in independent reading of echo textbooks or echo related articles? _____
13. How many hours would you estimate that you have spent with the TEE simulator? _____
14. How many hours a week do you currently spend playing video games? _____
15. What is your overall satisfaction with the TEE teaching you have received?
   Very unsatisfied Unsatisfied Neutral Satisfied Very satisfied
16. How would you rate the TEE training that you have received?
   Poor Fair Average Above Average Excellent
17. How would you rank your interactions with TEE attendings?
   Poor Fair Average Above Average Excellent
18. What is your overall comfort level with performing the technical aspects of a complete TEE exam?
   Poor Fair Average Above Average Excellent
19. What is your overall comfort level with interpretation of a normal TEE exam?
   Poor Fair Average Above Average Excellent
20. What is your overall comfort level with interpretation of an abnormal TEE exam?
   Poor Fair Average Above Average Excellent
21. How would you rank your ability to perform a complete TEE exam?
   Poor Fair Average Above Average Excellent
22. How would you rank your ability to interpret a TEE exam?
   Poor Fair Average Above Average Excellent
23. If you have spent time with the TEE simulator, how would you rank the utility of this as a training tool?