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Effectiveness of Simulation-Based Training on Transesophageal Echocardiography Learning
The SIMULATOR Randomized Clinical Trial

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IMPORTANCE Evidence is scarce on the effectiveness of simulation-based training in transesophageal echocardiography (TEE).

OBJECTIVE To assess the effectiveness of simulation-based teaching vs traditional teaching of TEE knowledge and skills of cardiology fellows.

DESIGN, SETTING, AND PARTICIPANTS Between November 2020 and November 2021, all consecutive cardiology fellows inexperienced in TEE from 42 French university centers were randomized (1:1; n = 324) into 2 groups with or without simulation support.

MAIN OUTCOMES AND MEASURES The co-primary outcomes were the scores in the final theoretical and practical tests 3 months after the training. TEE duration and the fellows' self-assessment of their proficiency were also assessed.

RESULTS While the theoretical and practical test scores were similar between the 2 groups (324 participants; 62.6% male; mean age, 26.4 years) before the training (33.0 [SD, 16.3] points vs 32.5 [SD, 18.5] points; $P = .80$ and 44.2 [SD, 25.5] points vs 46.1 [SD, 26.1] points; $P = .51$, respectively), the fellows in the simulation group (n = 162; 50%) displayed higher theoretical test and practical test scores after the training than those in the traditional group (n = 162; 50%) (47.2% [SD, 15.6%] vs 38.3% [SD, 19.8%]; $P < .001$ and 74.5% [SD, 17.7%] vs 59.0% [SD, 25.1%]; $P < .001$, respectively). Subgroup analyses showed that the effectiveness of the simulation training was even greater when performed at the beginning of the fellowship (ie, 2 years or less of training) (theoretical test: an increase of 11.9 points; 95% CI, 7.2-16.7 vs an increase of 4.25 points; 95% CI, −1.05 to 9.5; $P = .03$; practical test: an increase of 24.9 points; 95% CI, 18.5-31.0 vs an increase of 10.1 points; 95% CI, 3.9-16.0; $P < .001$). After the training, the duration to perform a complete TEE was significantly lower in the simulation group than in the traditional group (8.3 [SD, 1.4] minutes vs 9.4 [SD, 1.2] minutes; $P < .001$, respectively). Additionally, fellows in the simulation group felt more ready and more confident about performing a TEE alone after the training (mean score, 3.0; 95% CI, 2.9-3.2 vs mean score, 1.7; 95% CI, 1.4-1.9; $P < .001$ and mean score, 3.3; 95% CI, 3.1-3.5 vs mean score, 2.4; 95% CI, 2.1-2.6; $P < .001$, respectively).

CONCLUSIONS AND RELEVANCE Simulation-based teaching of TEE showed a significant improvement in the knowledge, skills, and self-assessment of proficiency of cardiology fellows, as well as a reduction in the amount of time needed to complete the examination. These results should encourage further investigation of clinical performance and patient benefits of TEE simulation training.

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Visual Abstract

Invited Commentary

Supplemental content

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Echocardiography is the cornerstone of current patient management in cardiology. Although the practice of transthoracic echocardiography (TTE) is taught from the beginning of the cardiology fellowship,[1-3] TEE learning may be hampered by the lack of availability of teachers and equipment. Furthermore, TEE is semi-invasive with a need for esophageal intubation. In this setting, simulation emerges as a key educational tool to improve accessibility of TEE training and accelerate the TEE learning curve.[4] Recent studies suggest that simulation-based TEE teaching shows significant benefits over conventional methods (based on didactic lectures) in improving introductory TEE skills and accelerating learning.[5-11] However, there is currently no consensus or recommendation regarding these programs, possibly explained by lack of evidence supporting simulation-based educational programs and the cost of TEE simulators.[12] Indeed, all studies assessing effectiveness of simulation-based TEE teaching were nonrandomized or randomized with a limited single-center sample size.[5,6,8,9,13-18] Therefore, the SIMULATOR study (a randomized study to assess the effect of Simulation-Based Training on Transesophageal Echocardiography Learning in Cardiology Fellows) was designed to assess the effectiveness of simulation-based training on TEE learning by comparing simulation-based teaching vs traditional teaching on the knowledge and skills of TEE among cardiology fellows in several French centers.[19] Our hypothesis is that TEE knowledge and skills may be enhanced by simulation-based TEE teaching.

Key Points

Question What is the effectiveness of simulation-based training on transesophageal echocardiography (TEE) knowledge and skills of cardiology fellows?

Findings In this multicenter randomized (1:1) clinical trial including 324 fellows from 42 French university centers, the fellows in the simulation group displayed higher theoretical test and practical test scores, needed less time to perform a complete TEE, and achieved better self-assessments of their proficiency than those in the traditional group 3 months after the training.

Meaning Simulation-based teaching of TEE should be considered to improve the knowledge, skills, and self-assessment of proficiency of cardiology fellows.

Methods

Study Design

Details regarding design of the SIMULATOR study have been published previously.[19] In brief, SIMULATOR was a multicenter, parallel-group, unblinded, randomized study in which all consecutive cardiology fellows of all training levels (year 1 to year 4) from 42 French centers were randomized (1:1) into either a TEE simulation group or to a traditional group. Fellows who had already performed a TEE, with or without supervision, were excluded. All fellows gave their consent to participate and agreed to provide their honest answers and thoughts about their skills and confidence in their practice. The data were collected by T.P. and A.C. on a secure server at Lariboisiere University Hospital (Paris). The study was conducted according to Consolidated Standards of Reporting Trials Extension (CONSORT Extension) reporting guidelines. The study was approved by the ethics committees of each center and authorized by the French data protection committee (Commission Nationale Informatique et Liberte). The study was registered retrospectively (ClinicalTrials.gov NCT05564507) due to the specifics of the included population (students and not patients), which did not require registration by the French authorities.

Theoretical and Practical Tests

Each fellow completed 2 sets of tests during the study: (1) a pretraining test before starting the training program to assess the baseline TEE level of each fellow; and (2) a final test performed 3 months after the end of the training program. Each of these tests included a theoretical test and a practical test on a TEE simulator (U/S Mentor Simulator; 3D Systems-Simbionix). Twenty-four certified national echocardiography teachers served as both trainers and raters in the study. To standardize the training and the practical test on the TEE simulator, all trainers followed a dedicated webinar of 30 minutes presenting the entire content of each session and the final test. The theoretical test included 20 online video-based questions to evaluate recognition of standard TEE views, normal anatomy, and some pathological cases, as already described.[7,14,17,18] The fellows were given 90 seconds for each question to choose the best answer from 5 multiple-choice propositions.[18] Each question was scored on a scale of 5 points (5 points if all propositions were correct and 0 point if at least 1 error was present), for a possible total of 100 points per test. These tests were designed and validated by 10 experts, all members of the Educational Committee within the French Group of Cardiovascular Imaging of the French Society of Cardiology, in charge of creating the examinations for the French national echocardiography diploma.

Immediately after each theoretical test (pretraining and final tests), all fellows underwent a practical test. Of note, all fellows in the 2 groups had 3 minutes before the practical test to familiarize themselves with the handling of the simulator, without specific training and before the probe introduction. The fellows were asked to show 10 basic views on the TEE simulator, as previously described[9,10] with a maximum of 1 minute for each view. The required views are presented in eFigure 1 in Supplement 1.[19] The teacher timed the duration between TEE probe introduction and obtention by the trainee of all 10 required views. The practical test was stopped after a maximum of 10 minutes. Each view was scored on a scale of 10 points using the modified Ferrero grading scale, for a possible total of 100 points for the practical test[8,9,18] (eTable 1 in Supplement 1). Of the possible 10 points per view, 5 were scored for imaging angle and overall clarity of the view (poor quality 0 points, average quality 2 points, optimal quality 5 points) and 5 assessed capturing all the pertinent anatomic structures in the view (−1 point per missing structure not shown, and 0 points if no structure identified). All trainers asked for the 10 basic views in a preestablished order.[19] These examinations were evaluated by the local teacher who was a nationally certified echocardiography teacher. At each center, the same teacher who conducted the simulation sessions was also the rater using the modified Ferrero scale. Each local teacher received a 1-hour training session via videoconference with 1 of the principal investigators of the study (T.P. or A.C.) to standardize the evaluation of the practical test using the TEE simulator. Overall, a maximum global score of 200 points could be obtained for each fellow at the end of each set of tests (ie, the sum of the theorical and practical tests). The simulator used for the practical test was the same one used for training the interventional group.

Randomization and Simulation-Based Training

Randomization with stratification by center was performed at the fellow level at a 1:1 ratio, by T.P. using computer-based software (Research Randomizer 4.0; Social Psychology Network) to assign all fellows to either the simulation group or the traditional group. Both groups took part in traditional didactic training using e-learning with a national free-access online course that is compulsory for all cardiology fellows in France. Beyond access to traditional e-learning, the simulation group attended 2 teaching sessions using a TEE simulator. The simulation session involved standardized initial teaching of normal cardiac findings, including anatomy of the mitral valve (with some mitral regurgitation cases), aortic valve, tricuspid valve, interatrial septum, and left atrial appendage, followed by demonstration of image acquisition by the teacher (time duration, 30 minutes).[19] Eighteen simulators were used for this study. Functionalities of TEE simulators have been described previously.[7] The duration of each session was 2 hours with a 6:1 student-to-instructor ratio. Each participant had dedicated 20 minutes of hands-on time to manipulate the probe and undertake a sequential TEE examination under supervision of the teacher. Other participants could watch their colleagues working on the simulator. The maximum time between the 2 simulation sessions was 2 months. In line with prior studies assessing the long-term knowledge retention of a simulation,[20] all fellows were invited to a final test to assess midterm knowledge 3 months after completing the training.

Fellows' Self-assessment of Proficiency and Satisfaction Assessment in the Simulation Group

The self-assessment of proficiency of all fellows was assessed with 4 standardized questions asked before and immediately after the training program: (1) "Do you feel ready to perform a TEE alone?" (2) "Do you feel confident enough to perform a TEE alone?" (3) "Do you feel comfortable with TEE probe introduction?" (4) "Do you feel comfortable with TEE probe manipulation?" Each question was graded from 1 (lowest grade) to 5 (highest grade). In the simulation group, satisfaction after the simulation training was assessed by an anonymous questionnaire including 6 statements on different aspects of the training, as previously published.[14]

End Points

The co-primary end points of the study were the differences between the 2 groups in the final theoretical and practical test scores after the training. The secondary end points were the differences in changes in the theoretical and practical test scores from pretraining to posttraining. In addition, we assessed the global score, defined as the sum of the theoretical and the practical test scores, the TEE examination duration, and fellows' self-assessment of their proficiency.

Statistical Analysis

Details regarding the determination of sample size have been reported previously.[19] Based on recent available literature[7,9,16] and considering the normalized 0- to 100-point score ranges for the 2 co-primary outcomes, a minimally important difference of 5 points (SD, 7 points) was considered for the differences in changes in the pretraining and posttraining scores on the theoretical and practical tests between the 2 randomized groups. Under these assumptions, a sample size of 50 participants per group (for an overall population of 100 participants) provides 90% power to detect a statistically significant difference between the 2 groups at a significance level of α = 2.5%, applying a Bonferroni correction to account for multiple testing of the 2 coprimary outcomes.

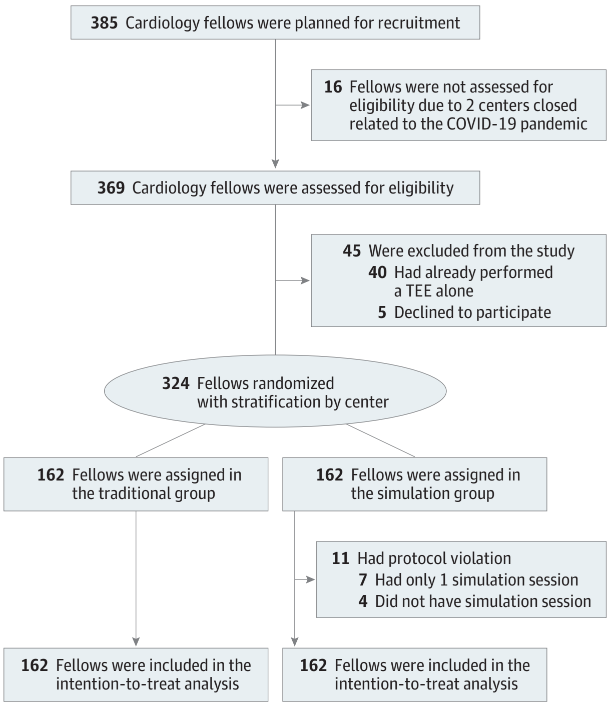
Continuous data are reported as mean (SD), as means for normally distributed data, or as medians and interquartile range (IQR) for nonnormally distributed data, as assessed through graphical methods and the Shapiro-Wilk test for normality. Categorical data are reported as counts and percentages. Between-group comparisons were performed using the *t* test or Mann-Whitney test for continuous variables and the χ^2 or Fisher exact test for categorical variables, as appropriate. Regarding the co-primary end points, nonparametric approaches (ie, Mann-Whitney tests) were used due to the skewed distribution of test scores previously described in the literature.[9] For within-group comparisons (pretest vs posttests), paired *t* tests and Wilcoxon signed rank tests were performed for continuous variables. Results from the subgroup analyses are presented using forest plots, based on linear regression model computing for the main end points; the differences between the randomized groups in changes from baseline in each subgroup are also shown, and global *P* values are reported from the interaction tests to assess the heterogeneity of findings across the subgroups of interest. Pearson or Spearman correlation coefficients were computed to explore correlations between changes in the scores and the pretraining scores. A 2-tailed $P < .03$ was considered statistically significant for the primary analyses and a 2-tailed $P < .05$ was used for all other comparisons. All data were analyzed according to the intention-to-treat principle using R software, version 3.6.3 (R Project for Statistical Computing; R Foundation) and Stata version 16.0 (StataCorp).

Results

Study Population

From November 2020 to November 2021, a total of 324 cardiology fellows from 42 centers were enrolled in the trial, with 162 randomly assigned to the TEE simulation group and 162 to the traditional group. The flowchart of the study is depicted in **Figure 1**. Participating centers and number of

Figure 1. Flowchart of the Study



Among the 385 cardiology fellows planned for recruitment, 369 fellows were assessed for eligibility in 42 French centers. Forty-five fellows were excluded from the study: 40 had already performed a transesophageal echocardiography (TEE) alone and 5 declined to participate. A total of 324 fellows were randomized with a stratification by center. Among the 162 fellows assigned to the simulation group, 11 had protocol violation, 7 had only 1 simulation session, and 4 did not have simulation session.

Table. Baseline Characteristics of the Study Population

Characteristics	No. (%) Simulation group (n = 162)	Traditional group (n = 162)
Age, mean (SD), y	26.4 (2.2)	26.4 (2.2)
Sex		
Male	94 (58.0)	109 (67.3)
Female	68 (42.0)	53 (32.7)
Year of training, mean (SD)	2.1 (1.1)	2.1 (1.1)
Previous national TTE certification		
None	117 (72.2)	118 (72.8)
1st year	27 (16.7)	28 (17.3)
2nd year	18 (11.1)	16 (9.9)
Willingness to specialize in cardiovascular imaging at the end of the fellowship	47 (29.0)	52 (32.1)
No. of TTEs previously performed alone		
<50	88 (54.3)	81 (50.0)
50-100	32 (19.8)	25 (15.4)
>100	42 (25.9)	56 (34.6)
No. of TEEs previously observed		
<5	64 (39.5)	74 (45.7)
5-20	68 (42.0)	54 (33.3)
>20	30 (18.5)	34 (21.0)
Playing video games in the past[a]	92 (56.8)	103 (63.6)
Currently playing video games	27 (16.7)	30 (18.5)

Abbreviation: TEE, transesophageal echocardiography.

[a] Defined as having played video games before the age of 18 years.

fellows included from each center are detailed in eTable 2 in Supplement 1. Two centers that had planned to participate were not open for recruitment due to COVID-19 university health regulations. Baseline characteristics of the fellows in the 2 groups were comparable (**Table**). The mean age of the population was 26.4 (SD, 2.2) years, with more men (63%), in the middle of their fellowship (mean year of training, 2.1 [SD, 1.1]; Table). Most did not have the national TTE and TEE diploma (72.5%) and one-third of the fellows were planning to specialize in cardiovascular imaging. Additionally, 20% of the fellows had observed more than 20 TEE examinations before the training.

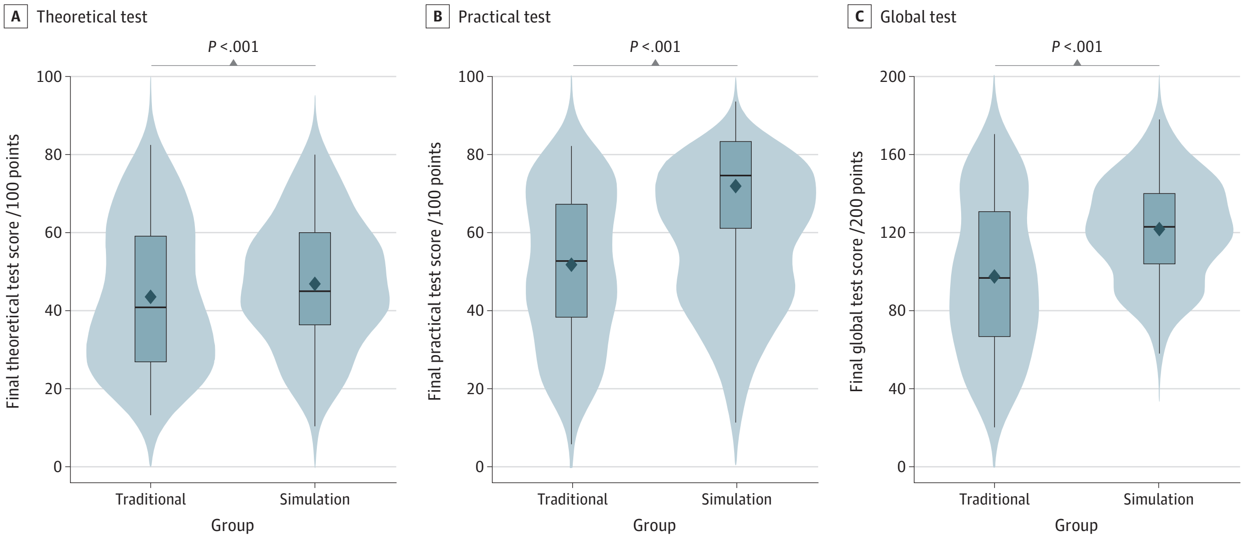
Comparison of Scores Between Groups

While the pretraining theoretical and practical test scores were comparable between the 2 groups (33.0 [SD, 16.3] points vs 32.5 [SD, 18.5] points; $P = .80$ and 44.2 [SD, 25.5] points vs 46.1 [SD, 26.1] points; $P = .51$, respectively), fellows in the simulation group displayed both higher final theoretical test scores (47.2 [SD, 15.6] points vs 38.3 [SD, 19.8] points; $P < .001$), and practical test scores (74.5 [SD, 17.7] points vs 59.0 [SD, 25.1] points; $P < .001$; **Figure 2**) than fellows in the traditional group after the training. Consistently, the final global score after the training program was also significantly higher in the simulation group (121.7 [SD, 22.7] points vs 97.3 [SD, 29.2] points; $P < .001$). The increases in theoretical test and practical test scores were greater in the simulation group than in the traditional group (an increase of 14.2% [SD, 16.2%] vs an increase of 5.8% [SD, 16.0%]; $P < .001$ and an increase of 30.3% [SD, 23.3%] vs an increase of 12.9% [SD, 18.3%]; $P < .001$, respectively). In addition, while TEE duration was comparable between the 2 groups before training (9.6 [SD, 1.0] minutes vs 9.5 [SD, 1.0] minutes; $P = .18$), it was significantly lower in the simulation group than in the traditional group after training (8.3 [SD, 1.4] minutes vs 9.4 [SD, 1.2] minutes; $P < .001$, respectively).

Subgroup Analyses

The greater increases from pretraining in the theoretical, practical, and global scores within the simulation group compared with the traditional group were globally consistent across all examined subgroups, as evidenced by the consistently positive differences between randomized groups (**Figure 3**). Regarding the theoretical test, the effectiveness of simulation training was greater in women (an increase of 13.4 points; 95% CI, 7.3-19.6 vs an increase of 5.5 points; 95% CI, 1.2-9.8; heterogeneity test $P = .03$) or when performed at the beginning of the fellowship (ie, 2 years or less of training: an increase of 11.9 points; 95% CI, 7.2-16.7 vs an increase of 4.25 points; 95% CI, −1.05 to 9.5; $P = .03$) and within the lowest pretraining theoretical test score tercile (Figure 3A). Regarding the practical test, the effectiveness of simulation training was greater at the beginning of the fellowship (2 years or less of training: an increase of 24.9 points; 95% CI, 18.5-31.0 vs an increase of 10.1;

Figure 2. Final Tests Score 3 Months After the Training in the Transesophageal Echocardiography (TEE) Simulation Group and in the Traditional Group



The fellows in the simulation group displayed higher final theoretical test (47.2 [SD,15.6] points vs 38.3 [SD, 19.8] points; $P < .001$) (A) practical test (74.5 [SD, 17.7] points vs 59.0 [SD, 25.1] points; $P < .001$) (B) and global test score (121.6 [SD, 25.3] points vs 97.3 [SD, 38.8] points; $P < .001$) (C) P value by t test. The median value was used as a cutoff for age (median, 26 years). Number of TTEs previously performed was divided in 3 groups (less than 50, 50 to 100 and more than 100), as well as the number of TEEs previously observed (less than 5, 5 to 20, more than 20). The pretraining test score was divided in terciles.

95% CI, 3.9-16.0; $P = .001$) and with fewer TTEs previously performed (less than 50 TTEs: an increase of 22.0 points; 95% CI, 15.8-28.0 vs 50 to 100 TTEs: an increase of 9.8 points; 95% CI, 0.12-19.0 vs more than 100 TTEs: an increase of 11.1 points; 95% CI, 3.5-19.0; $P = .02$) or fewer TEEs previously observed (less than 5 TEEs: an increase of 23.4 points; 95% CI, 16.3-31.0 vs 5 to 20 TEEs: an increase of 12.6 points; 95% CI, 5.3-20.0 vs more than 20 TEEs: an increase of 14.6 points; 95% CI, 6.1-23.0; $P = .01$) (Figure 3B). These findings were similar for the global test score (eFigure 2 in Supplement 1). There was no interaction between prior or current experience of video games and the effect of the simulation-based training (an increase of 29.7 points; 95% CI, 21.1-38.0 vs an increase of 23.1 points; 95% CI, 15.2-31.0; $P = .28$ and an increase of 25.9 points; 95% CI, 19.8-32.0 vs an increase of 24.8 points; 95% CI, 7.6-42.0; $P = .88$, respectively).

Correlations between changes in scores and pretraining scores are provided in eFigure 3 in Supplement 1. Briefly, the changes in scores were consistently greater when the pretraining scores were lower. This association was stronger in the simulation group than in the traditional group.

Changes in Fellows' Self-assessment of Proficiency and Satisfaction Assessment in the Simulation Group

After the training program, fellows in the simulation group felt more ready and more confident about performing a TEE alone (mean score, 3.0; 95% CI, 2.9-3.2 vs mean score, 1.7; 95% CI, 1.4-1.9; $P < .001$ and mean score, 3.3; 95% CI, 3.1-3.5 vs mean score, 2.4; 95% CI, 2.1-2.6; $P < .001$, respectively; **Figure 4**). To the statement "I enjoyed attending the training," the response was positive in 85.2% answers. The response was 89.5% positive to the question "I found the training useful," 82.7% of the fellows agreed or strongly agreed that the duration of the teaching was correct, 85.2% agreed that the simulation program was relevant for their level of training, and 89.5% expected to improve on their final test. All fellows were positive (86.4%) or neutral (13.6%) about recommending the training to others. Additionally, the mean satisfaction score was 27.0 (SD, 2.9) points out of a total of 30 points. The detailed satisfaction assessment in the simulation group based on a Likert scale is provided in eFigure 4 in Supplement 1.

Discussion

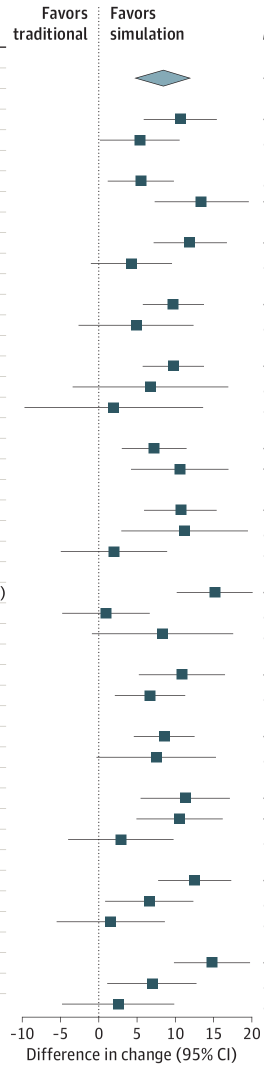
The randomized SIMULATOR trial assessed the effectiveness of simulation-based training on TEE learning. Among 324 cardiology fellows from 42 French centers, we demonstrated that simulation-based training was associated with higher theoretical, practical, and global test scores compared with traditional education 3 months after the training. In addition, (1) the effect of the simulation-based training was greater among fellows at the beginning of fellowship (ie, 2 years or less of training) in both theorical and practical tests and in women for the theoretical test; (2) simulation-based training was associated with a shorter TEE examination duration after training; and (3) fellows' self-assessment of their proficiency was better in the simulation group across all components.

Beyond the technological enthusiasm, the importance of simulation in TEE remains debated. Although some nonrandomized or single-center studies have shown improvements in psychomotor skills and understanding of anatomy after simulation-based TEE training,[6,8,9,14,18] a meta-analysis showed little compelling evidence from published studies to support

Figure 3. Subgroup Analysis

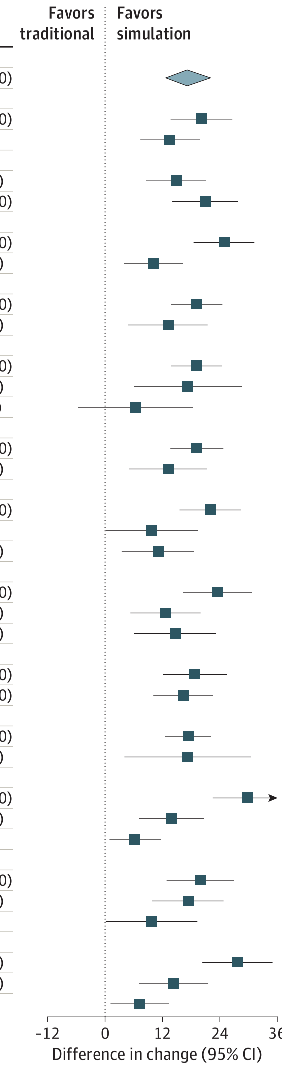
A Theoretical test score

Outcome	Group 1 traditional	Group 2 simulation	Difference in change (95% CI)	*P* value	Heterogeneity *P* value
Change in theoretical score					
Overall	5.80 (16.0)	14.2 (16.2)	8.37 (4.85 to 11.90)	<.001	
Age, y					
≤26	5.96 (16.0)	16.6 (16.9)	10.70 (5.90 to 15.40)	<.001	.14
>26	5.58 (16.1)	10.9 (14.9)	5.35 (0.15 to 10.50)	.04	
Gender					
Men	7.42 (15.7)	12.9 (15.4)	5.50 (1.19 to 9.80)	.01	.03
Women	2.45 (16.3)	15.9 (17.4)	13.40 (7.29 to 19.60)	<.001	
Years of training					
≤2	4.31 (15.5)	16.2 (16.3)	11.90 (7.18 to 16.70)	<.001	.03
>2	7.85 (16.6)	12.1 (16.1)	4.25 (−1.05 to 9.50)	.11	
National TTE certification					
No	5.42 (15.7)	15.1 (15.2)	9.70 (5.74 to 13.70)	<.001	.23
Yes	6.80 (17.0)	11.7 (18.6)	4.87 (−2.65 to 12.40)	.20	
National TTE certification					
No	5.42 (15.7)	15.1 (15.2)	9.70 (5.74 to 13.70)	<.001	.63
1st y	6.39 (18.0)	13.1 (19.6)	6.76 (−3.40 to 16.90)	.18	
2nd y	7.50 (15.8)	9.44 (17.4)	1.94 (−9.72 to 13.60)	.73	
Willingness to specialize in imaging					
No	7.41 (16.4)	14.7 (15.9)	7.24 (3.00 to 11.50)	<.001	.38
Yes	2.38 (14.7)	13.0 (17.2)	10.60 (4.23 to 17.00)	<.001	
No. of TTE previously performed					
<50	5.86 (15.7)	16.5 (15.4)	10.70 (5.96 to 15.40)	<.001	.77
50-100	3.60 (13.4)	14.8 (16.9)	11.20 (2.97 to 19.50)	.009	
>100	6.68 (17.6)	8.69 (16.7)	2.01 (−4.97 to 9.00)	.56	
No. of TEE previously observed					
<5	3.11 (14.2)	18.3 (15.0)	15.20 (10.20 to 20.10)	<.001	.30
5-20	9.06 (14.0)	10.0 (17.1)	0.94 (−4.77 to 6.70)	.74	
>20	6.47 (21.2)	14.8 (14.8)	8.36 (−0.91 to 17.60)	.07	
Playing videogames in the past					
No	4.39 (14.3)	15.3 (17.3)	10.90 (5.29 to 16.50)	<.001	.25
Yes	6.60 (16.9)	13.3 (15.4)	6.71 (2.12 to 11.30)	.004	
Currently playing videogames					
No	5.79 (16.3)	14.3 (16.7)	8.55 (4.58 to 12.50)	<.001	.82
Yes	5.83 (15.1)	13.3 (14.1)	7.50 (−0.29 to 15.30)	.05	
Pretraining practical test score tertile					
1st	2.37 (15.4)	13.6 (15.6)	11.30 (5.46 to 17.10)	<.001	.02
2nd	5.90 (13.7)	16.5 (15.4)	10.60 (4.95 to 16.20)	<.001	
3rd	9.20 (17.9)	12.1 (17.8)	2.90 (−3.99 to 9.80)	.40	
Pretraining theoretical test score tertile					
1st	9.58 (13.9)	22.1 (14.2)	12.50 (7.80 to 17.30)	<.001	<.001
2nd	7.02 (16.1)	13.6 (14.1)	6.61 (0.86 to 12.40)	.02	
3rd	−1.88 (16.8)	−0.294 (13.5)	1.59 (−5.48 to 8.70)	.65	
Pretraining global test score tertile					
1st	4.64 (11.1)	19.5 (15.0)	14.80 (9.88 to 19.80)	<.001	.64
2nd	6.84 (14.6)	13.8 (15.4)	7.00 (1.16 to 12.80)	.01	
3rd	6.04 (20.7)	8.6 (16.8)	2.56 (−4.74 to 9.90)	.48	



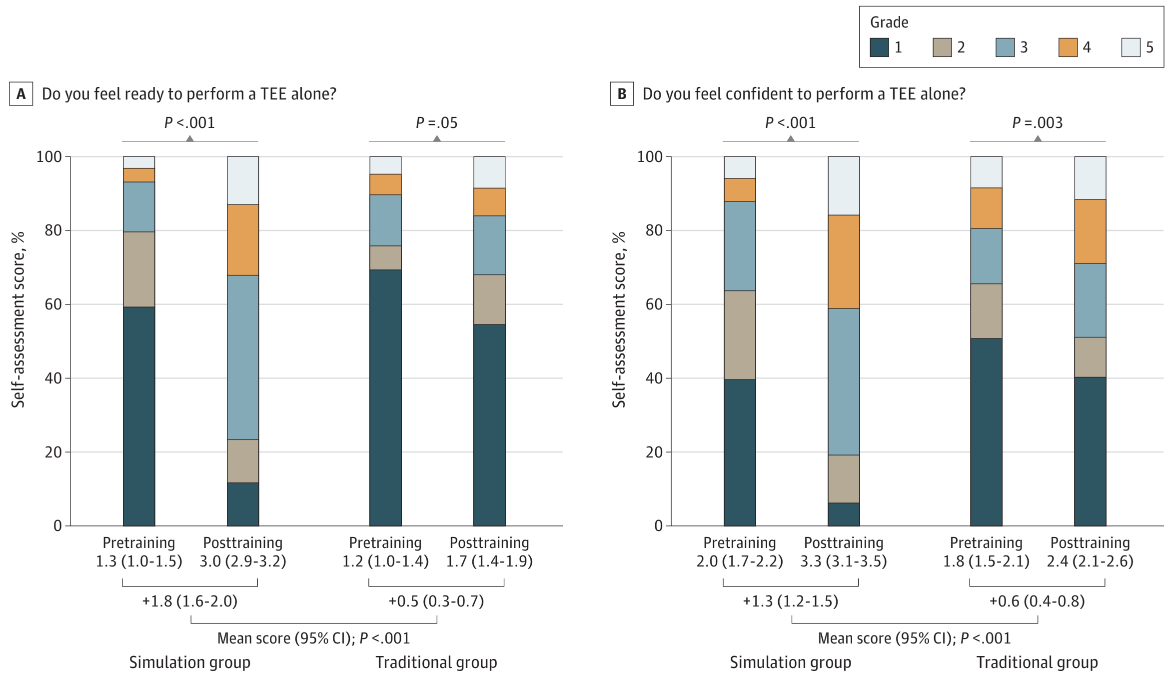
B Practical test score

Outcome	Group 1 traditional	Group 2 simulation	Difference in change (95% CI)	*P* value	Heterogeneity *P* value
Change in practical score					
Overall	12.9 (18.3)	30.3 (23.3)	17.30 (12.80 to 22.00)	<.001	
Age, y					
≤26	14.9 (19.9)	35.1 (23.8)	20.20 (13.80 to 27.00)	<.001	.15
>26	10.3 (15.7)	24.0 (21.1)	13.6 (7.40 to 20.00)	<.001	
Gender					
Men	13.3 (19.5)	28.2 (24.8)	14.90 (8.77 to 21.00)	<.001	.21
Women	12.2 (15.7)	33.1 (20.8)	20.90 (14.10 to 28.00)	<.001	
Years of training					
≤2	13.6 (19.0)	38.4 (23.6)	24.90 (18.50 to 31.00)	<.001	<.001
>2	12.1 (17.4)	22.1 (19.9)	10.10 (3.93 to 16.00)	.002	
National TTE certification					
No	15.2 (18.8)	34.3 (22.3)	19.10 (13.80 to 24.00)	<.001	.23
Yes	6.7 (15.6)	19.8 (22.8)	13.10 (4.83 to 21.00)	.002	
National TTE certification					
No	15.2 (18.8)	34.3 (22.3)	19.10 (13.80 to 24.00)	<.001	.25
1st y	5.36 (17.4)	22.7 (24.0)	17.30 (6.05 to 29.00)	.003	
2nd y	9.06 (12.0)	15.4 (20.7)	6.30 (−5.71 to 18.00)	.29	
Willingness to specialize in imaging					
No	12.3 (19.2)	31.4 (23.0)	19.10 (13.60 to 25.00)	<.001	.24
Yes	14.2 (16.4)	27.4 (24.1)	13.20 (5.04 to 21.00)	.002	
No. of TTE previously performed					
<50	16.4 (19.3)	38.4 (22.6)	22.00 (15.60 to 28.00)	<.001	.01
50-100	13.0 (16.1)	22.8 (19.5)	9.80 (0.12 to 19.00)	.04	
>100	7.89 (16.8)	19.0 (21.0)	11.10 (3.47 to 19.00)	.005	
No. of TEE previously observed					
<5	15.9 (19.1)	39.3 (23.3)	23.40 (16.30 to 31.00)	<.001	.009
5-20	13.9 (17.1)	26.5 (22.6)	12.60 (5.25 to 20.00)	<.001	
>20	4.88 (16.5)	19.5 (17.8)	14.60 (6.05 to 23.00)	<.001	
Playing videogames in the past					
No	12.3 (14.7)	31.1 (22.0)	18.80 (12.10 to 26.00)	<.001	.61
Yes	13.3 (20.1)	29.7 (24.3)	16.40 (10.10 to 23.00)	<.001	
Currently playing videogames					
No	12.7 (17.5)	30.1 (22.4)	17.40 (12.50 to 22.00)	<.001	.98
Yes	13.7 (21.7)	31.0 (28.0)	17.30 (4.04 to 30.00)	<.001	
Pretraining practical test score tertile					
1st	19.3 (20.4)	49.1 (18.4)	29.70 (22.50 to 37.00)	<.001	<.001
2nd	16.2 (17.1)	30.1 (17.9)	13.90 (7.11 to 21.00)	<.001	
3rd	3.54 (12.6)	9.8 (14.8)	6.30 (0.97 to 12.00)	<.001	
Pretraining theoretical test score tertile					
1st	13.0 (18.4)	32.9 (23.4)	19.90 (12.90 to 27.00)	<.001	.29
2nd	16.6 (17.0)	34.0 (21.3)	17.30 (9.80 to 25.00)	<.001	
3rd	8.81 (19.1)	18.5 (23.4)	9.70 (0.01 to 19.00)	.05	
Pretraining global test score tertile					
1st	17.9 (18.9)	45.6 (20.0)	27.7 (20.40 to 35.00)	<.001	<.001
2nd	17.3 (17.6)	31.6 (19.6)	14.30 (7.09 to 22.00)	<.001	
3rd	4.33 (15.2)	11.6 (16.7)	7.30 (1.19 to 13.00)	.02	



TEE indicates transesophageal echocardiography.

Figure 4. Change in Self-assessment of Proficiency of Fellows



Each question was graded from 1 (lower grade) to 5 (higher grade). *P* values by χ^2 for trend or paired *t* test.
TEE indicates transesophageal echocardiography.

the widespread adoption of TEE simulation.[11] Our multicenter randomized trial supports the use of simulation-based training in TEE to improve skills, knowledge, and confidence of cardiology fellows. While most previous studies assessed participants' retention in only short-term recall 1 week after TEE education,[14] the current study assessed midterm recall 3 months after the training ended. These results obtained with only two 2-hour simulation sessions suggest improved retention of TEE knowledge and skills with simulation compared with traditional teaching. Moreover, randomized stratification by center reduced the bias of variability in the quality and effectiveness of instructors, which is an essential step in the validation of an educational program.[4] Interestingly, the improvement in TEE knowledge and skills was greater at the beginning of the fellowship (ie, 2 years or less of training), highlighting importance of starting this training as early as possible during the curriculum. However, it is important to note that approximately 20% of the fellows had observed more than 20 TEE examinations before randomization, suggesting that these fellows were more advanced in their training. Interestingly, in these fellows, there was no significant improvement in the theoretical score and improvement in practical scores was similar compared with other fellows. These findings highlight the importance of hands-on training to develop practical skills instead as being a bystander observer. Notably, the effect of the simulation-based training was greater in women compared with men regarding the theoretical test, a finding in line with prior reports suggesting that women are more able to sustain their performance during a cognitive test.[21] Although simulation-based training was associated with a statistically significant reduction of 1.1 minutes in TEE examination duration after the training, the clinical effect of this difference in a clinical routine seems quite limited and deserves further investigation. While there was significantly greater comfort with handling the probe in the simulation group, there was no difference in comfort with probe introduction between the 2 groups. These findings are consistent with prior reports that highlight that current simulators lack simulation of probe introduction and only simulate probe manipulation for image acquisition.[4,12] Probe insertion should be an axis of technological improvement for TEE simulators in the future.

The simulation-based training program in this study, with only two 2-hour sessions, is not sufficient to achieve an expert level in TEE, but even with such a limited simulation-based program in our study, the benefits of improved knowledge and skills were statistically significant. Therefore, this study provides evidence in favor of simulation-based training in TEE. However, the final results of the simulation group remain moderate with a mean theoretical score of 47 of 100 points and mean practical score of 74 of 100 points. Most current TEE simulation training programs rely on a larger number of simulator sessions with more manipulation time.[12] Thus, these results also highlight the difference between improving TEE skills and becoming autonomous in performing a TEE alone.

Limitations

This study has some limitations. First, fellows in the simulation group manipulated the TEE probe during the training sessions, which may favor them over fellows in the traditional group who did not handle any TEE probe during training. However, to minimize this bias, all fellows were given a 3-minute hands-on with probe and simulator without any instruction to become familiar with the TEE simulator before beginning the practical test. Second, we cannot exclude the possibility that the traditional group underwent more online training than the simulation group. In addition, the number of TEEs performed by fellows between the beginning of the study and end of the study was not collected. Nevertheless, in this randomized trial, we assume that this was similar between groups. Third, the protocol design of the study limited the time for simulation-based training, which was relatively modest compared with the usual norm for such simulation-based training. Fourth, probe insertion itself is not a component of TEE simulation. As this is an essential skill required for independent performance of TEE, this must be a target for technological improvement in TEE simulators in the future.

Although the simulators used in this trial allow for acquisition of transgastric TEE views, we did not investigate these views in line with prior published studies using the list of 10 basic TEE views.[7,9] Because the trial was not blinded, it is possible that the Hawthorne effect may have improved fellows' self-perception scores. In addition, the fellows' self-assessment of proficiency may be limited by the Dunning-Kruger effect corresponding to a cognitive bias whereby people with low ability for a given task overestimate their ability. This study was not designed to assess the performance of fellows in performing TEE in real patients and data regarding clinical TEE performed between the training and test were not collected. For these reasons, the trial does not provide evidence of clinical benefit for patients resulting from simulation training. Additionally, because there was no immediate posttest after training, the 3 months posttest could not directly measure the retention or degradation of knowledge and skills in TEE.

Conclusions

This multicenter randomized trial shows that simulation-based teaching in TEE results in a significant improvement in knowledge, skills, and confidence of cardiology fellows, as well as a reduction in TEE time. These results should encourage further investigation of clinical performance and patient benefits of TEE simulation training.

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