Practice improves performance on a coronary anastomosis simulator, attending surgeon supervision does not

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Objectives: Enthusiasm for simulation early in cardiothoracic surgery training is growing, yet evidence demonstrating its utility is limited. We examined the effect of supervised and unsupervised training on coronary anastomosis performance in a randomized trial among medical students.

Methods: Forty-five medical students were recruited for this single-blinded, randomized controlled trial using a low-fidelity simulator. After viewing an instructional video, all participants attempted an anastomosis. Subsequently, the participants were randomized to 1 of 3 groups: control (n = 15), unsupervised training (n = 15), or supervised training with a cardiothoracic surgeon or fellow (n = 15). Both the supervised and unsupervised groups practiced for 1 hour per week. After 4 weeks, the participants repeated the anastomosis. All pre- and post-training performances were videotaped and rated independently by 3 cardiothoracic surgeons blinded to the randomization. All raters scored 13 assessment items on a 1 to 5 (low-high) scale along with an overall pass/fail rating.

Results: After the training period, all 3 groups showed significant improvements in composite scores (control: $+0.52 \pm 0.69$ [$P = .014$], unsupervised: $+1.05 \pm 0.48$ [$P < .001$], and supervised: $+1.10 \pm 0.84$ [$P < .001$]). Compared with control group, both supervised ($P = .005$) and unsupervised trainees ($P = .005$) demonstrated a significant improvement. Between the supervised and unsupervised groups there were no statistically significant differences in composite scores.

Conclusions: Practice on low-fidelity simulators enabled trainees to improve on a broad range of skills; however, the additional effect of attending-level supervision is limited. In an era of increasing staff surgeon responsibilities, unsupervised practice may be sufficient for inexperienced trainees. (*J Thorac Cardiovasc Surg* 2015;149:12-7)

See related commentary on page 18.

Supplemental material is available online.

Simulation training is now a mandated component of cardiothoracic (CT) surgical training,¹ with a variety of low- and high-fidelity models available.^{2,3} A tool developed by the Joint Council on Thoracic Surgery

Education (JCTSE) for evaluating competence in coronary anastomosis performance has shown high interrater reliability and internal consistency for simulation models,⁴ and is being used to assess simulation training effectiveness. Under the sponsorship of the JCTSE and Thoracic Surgery Directors Association, a nationwide invitation to CT resident physicians to participate in a simulation training competition culminated in recognition of the top winners at the 2013 American Association of Thoracic Surgeons Annual Conference.⁵ However, an optimal method of teaching CT surgical tasks has yet to be demonstrated. We conducted a randomized study of medical students' performance of a coronary anastomosis on a low-fidelity simulator to determine the effects of supervision and practice.

MATERIALS AND METHODS

Participants

Forty-five medical students were recruited through a school-wide list-serv E-mail, with all consenting respondents accepted until the sample size to achieve adequate statistical power was obtained. The primary end point was composite score after the training period. With 15 participants per group there is 80% power to detect a change of 1 standard deviation unit in the primary end point between the 3 groups at a 2-sided 5% type I error level. No compensation was offered and approval was granted from the Institutional Review Board at Northwestern University. The participant

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Abbreviations and Acronyms

CT = cardiothoracic
JCTSE = the Joint Council on Thoracic Surgery Education

pool had a mean age of 23 ± 1.7 years, was 51.1% female, and the majority were first-year students (66.7% M1, 28.9% M2, and 4.4% M3).

Study Design

The task consisted of a simulated end-to-side coronary anastomosis using a low-fidelity simulator. All subjects viewed a short video demonstrating the steps of the task, after which they performed a task attempt that was video-recorded. Each of the 13 components of the JCTSE assessment tool were correctly illustrated and viewing was unrestricted. Using portable synthetic tube task stations, each participant was to anastomose a 5-mm synthetic tube (Limbs & Things, Savannah, Ga) in an end-to-side fashion onto a similar tube mounted on a plastic board (W.L. Gore & Associates, Inc, Flagstaff, Ariz). Surgical instruments were similar to those used in the operating room, and suture used was 5-0 polypropylene. All participants were administered a questionnaire documenting demographics, prior surgical experience, career plans, and level of interest in surgery, CT surgery, and simulation. Responses were measured using a 5-point Likert scale (where 1 = strongly disagree and 5 = strongly agree).

Students were then randomized in a 1:1:1 manner to a control group, unsupervised training group, or supervised training group after they completed the initial training session (Figure 1). The control group underwent no further training. The unsupervised training group was asked to perform 1 hour of training over 4 different sessions over a period of 1 month. This training consisted of anastomotic task completion on a provided at-home low-fidelity model. The supervised training group spent the same amount of time performing the task, but under the instruction of a cardiac surgeon or resident physician. Direct, constructive, verbal feedback was provided at each session for the supervised training group with a ratio of 3 to 4 students per instructor. At the conclusion of the 4-week training period, all participants returned for a posttest session where they were recorded performing an anastomosis and again completed the questionnaire.

These recorded anastomoses were then rated in a blinded fashion by 3 senior cardiac surgeons utilizing the JCTSE Assessment Tool. Each video recording was anonymous as to the identity of the participant. The raters were unrestricted in their time to grade the videos. The raters did not have direct, physical access to the simulated anastomoses performed. This rating scale consists of 13 assessment items on a 1 to 5 (low-high) scale as well as an overall pass/fail rating (Figure E1). The assessment items were averaged into a composite score, from which the arteriotomy skill was removed due to lack of rater agreement. In addition, the participants rated their own anastomoses performance using this scale at the pre- and posttraining sessions.

Statistical Analysis

Generalized estimating equations were used to compare the primary end point of rater-based pre- and posttraining composite score and pass/fail rates among the control, unsupervised practice, and supervised practice groups. Self-evaluations in pre- and posttraining composite score and pass/fail rates were assessed in similar fashion. The relationship between interest and training group was also modeled as a function of type of training (group), rater and the respective pretraining score using a 3-dimensional posttraining response (1 score per rater). Statistical significance was established at the 2-sided 5% alpha level and there were no adjustments for multiplicity. Composite scores are reported as mean $\pm$ standard deviation.

RESULTS

Performance Scores by Senior Rater Evaluation

All 3 groups demonstrated improvement in senior-rated composite scores (Table 1 and Figure 2); control: 1.93 to 2.45 ($+0.52 \pm 0.69$ [$P = .014$]), unsupervised: 2.04 to 3.09 ($+1.05 \pm 0.48$ [$P < .001$]), and supervised: 2.05 to 3.15 ($+1.10 \pm 0.84$ [$P < .001$]). Both supervised ($P = .005$) and unsupervised trainees ($P = .005$) demonstrated a significant improvement compared with the control group. Both practice groups demonstrated significant improvement across the majority of the technical skills categories (Table 1). Significantly higher pass rates occurred in the supervised practice group (55%) and unsupervised practice group (58%) compared with control (36%; $P = .005$). Between the supervised and unsupervised groups there were no statistically significant differences in composite individual task, or pass/fail scores. The interrater agreements for pretraining and posttraining composite scores were 0.92 and 0.71, respectively, demonstrating good agreement between raters.

Performance Scores by Participant Self-Evaluation

Across groups and at both pre- and posttraining, participant self-rated composite scores were similar to the senior-rater scores (Figure 3). In pass-fail assessments, participant-rated pass rates were higher than senior-rated pass rates across all groups. This difference was greatest in the final evaluation of the supervised practice group, where 100% of participants determined themselves to have passed, versus a 55% pass rate by senior raters (Table 2). The gap between participant-rated and senior-rated final pass rates was smaller in the unsupervised (69% vs 58%) and control groups (53% vs 36%).

Interest in Surgery

Previously published data from this medical student cohort demonstrated that supervision led to an increase in interest in surgery ($P < .028$) compared with the control group.⁶ We compared participants in the top 50% and bottom 50% of improvement (defined as initial score subtracted from final score), to determine if there was a relationship between score improvement and change in interest in a career in surgery. We found no relationship between improvement in score and interest in surgery ($P = .47$) based on the raters' evaluations. However, an increased interest in a career in surgery was found among the top 50% improvement group when self-evaluation scores were used ($P < .048$).

DISCUSSION

This prospective, randomized study with blinded expert raters demonstrated that practice on coronary simulators improves performance across a broad range of skills.

FIGURE 1. Study design.

However, the additional effect of attending-level supervision did not significantly improve composite scores or pass/fail rates.

Further, despite similar pass rates as determined by senior-raters, participants with attending-level supervision were more likely to grant themselves a passing score. The discordance between rater- and self-pass/fail agreement for the supervised group compared with the unsupervised and control groups suggests that even brief technical mentorship influences perception of performance. Although the unsupervised group practiced for an equal amount of

time and demonstrated parallel composite score improvement, this group did not share the large increase in self-evaluated technical ability.

Several randomized simulation studies have investigated practice conditions using similar objective assessment measures. A controlled study⁷ with M1 students who practiced suturing and knot-tying skills for 1 hour compared self-directed practice to concurrent expert feedback and summary expert feedback. Each of the 3 practice groups improved more than controls. However, at 1-month retention testing, only the self-directed practice and

TABLE 1. Effect of type of training on composite score and individual item scores

	Control (n = 14)		Unsupervised (n = 12)		Supervised (n = 14)		P value†		
Count*	Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining	Unsupervised vs control	Supervised vs control	Supervised vs unsupervised
Composite score	1.93 ± 0.62	2.45 ± 0.93§	2.04 ± 0.57	3.09 ± 0.88§	2.05 ± 0.63	3.15 ± 0.95§	.005	.005	.792
Individual item									
Arteriotomy	2.23 ± 0.76	2.69 ± 0.92§	2.25 ± 0.65	3.11 ± 0.75§	2.21 ± 0.78	3.10 ± 0.91§	.108	.061	.714
Graft orientation	2.21 ± 0.84	2.74 ± 0.99§	2.22 ± 0.80	3.31 ± 0.89§	2.31 ± 0.78	3.26 ± 0.89§	.015	.025	.979
Bite	1.81 ± 0.92	2.38 ± 1.21	1.78 ± 0.87	3.17 ± 1.00§	1.88 ± 0.83	3.10 ± 1.14§	.007	.015	.865
Spacing	1.74 ± 0.89	2.50 ± 1.17§	1.86 ± 0.87	3.17 ± 0.97§	1.76 ± 0.85	3.19 ± 1.15§	.015	.022	.737
Needle holder use	2.02 ± 0.78	2.71 ± 1.20§	2.22 ± 0.87	3.08 ± 1.11§	2.24 ± 0.98	3.19 ± 1.13§	.247	.123	.589
Use of forceps	1.76 ± 0.85	1.76 ± 1.01	1.89 ± 0.89	2.92 ± 1.20§	1.93 ± 0.78	3.00 ± 1.23§	.002	.001	.855
Needle angles	1.69 ± 0.81	2.43 ± 1.11§	1.75 ± 0.77	3.00 ± 1.12§	1.74 ± 0.77	3.02 ± 1.09§	.023	.016	.761
Needle transfer	1.79 ± 0.92	2.50 ± 1.19§	2.00 ± 0.86	3.17 ± 1.11§	2.07 ± 0.95	3.26 ± 1.14§	.021	.006	.607
Suture management	1.90 ± 0.76	2.50 ± 1.09§	2.08 ± 0.81	2.94 ± 0.92§	2.12 ± 0.74	3.10 ± 0.98§	.054	.030	.558
Knot tying	1.67 ± 0.69	1.98 ± 1.07§	1.78 ± 0.87	2.83 ± 1.32§	1.69 ± 0.78	3.02 ± 1.20§	.003	.000	.415
Hand mechanics	2.07 ± 0.81	2.74 ± 1.15§	2.39 ± 0.80	3.42 ± 1.11§	2.26 ± 0.86	3.33 ± 1.10§	.022	.046	.865
Use of both hands	2.19 ± 0.77	2.33 ± 1.10	2.14 ± 0.90	3.17 ± 0.97§	2.29 ± 0.83	3.24 ± 1.05§	.002	.001	.898
Economy of time	1.95 ± 0.82	2.60 ± 1.06§	2.14 ± 0.68	2.92 ± 0.94§	2.21 ± 0.90	3.17 ± 1.10§	.325	.042	.249

Values are presented as mean ± standard deviation. *Count includes only participants who completed both pretraining and posttraining performances in each group. †Generalized estimating equations analysis with posttraining score as the response variable, rater/type of training as the explanatory variable, and pretraining score as the covariate. §Demonstrated significant improvement ($P < .05$) using generalized estimating equations with repeated measures.

FIGURE 2. Scatterplot of raters' initial versus final average composite score.

summary feedback groups were superior to controls. A crossover study showed no difference between self-directed practice and expert-directed group practice when first- and second-year surgical resident physicians trained on skin excision/closure and bowel anastomosis.⁸ After an expert-guided tutorial that included expert feedback practices, first- and second-year resident physicians from various surgical specialties were randomly assigned to no additional practice or self-directed practice on a low-fidelity coronary anastomosis model.⁹ Posttesting was conducted on an in-vivo porcine carotid artery. Self-directed practice resulted in better performance on all measures. These studies suggest that self-directed practice enhances training or results in performance that is

generally as good as, or better than, expert feedback practice, as seen in our study.

Our study is limited in several respects. The duration was 1 month and for the practice groups training occurred only 1 hour per week. More practice time may have yielded a higher rate of improvement. Yet we aimed to measure the role of supervision, and this necessitated an equal training time between the supervised and unsupervised training groups. The training time of the supervised group was limited by coordination of faculty and medical student availability. Our study used a trainee-to-trainer ratio of 3:1 or 4:1, higher than traditionally used in the operating room (ie, 1:1). Nesbit and colleagues¹⁰ were able to demonstrate, with 1:1 practice over a 4-month period, that medical students performed at a skill level comparable to that of senior-level general surgery residents. Although the introductory video did demonstrate all JCTSE assessment areas, it may not have represented the best possible preparation for this study population. A thorough, lengthened curriculum illustrating basic surgical techniques contributing to competency in anastomosis would likely have benefited these relative novices. In addition, the type of feedback provided by faculty and fellows for students in the supervised practice group may have varied over the several sessions. Whereas the training provided was geared toward JCTSE assessment areas, specific guidance was not provided in the context of a formalized curriculum. This can be viewed as a weakness of the study, or as an approximation of flexible training time geared toward the trainees' specific needs. In addition, our single-institution study included only preclinical medical students who expressed an interest in surgical skills, and does not necessarily represent early CT surgery trainees. Lastly, we focused on a basic technique; as a result these

FIGURE 3. Boxplots of differences in composite score (self minus rater) by group: Initial and final (*P* values based on Wilcoxon rank sum test).

TABLE 2. Pass/fail summaries at initial and final assessment

Group	Self-assessment			Rater assessment		
	Initial	Final	P value	Initial	Final	P value
Control	33	53	.08	31	36	.48
Unsupervised	62	69	.74	28	58	<.001
Supervised	36	100	NA	26	55	<.001
Overall	43	74	.005	28	49	<.001

Values are presented as %. NA, Not applicable.

findings may not necessarily extrapolate to the larger picture of complex technical skills and decision making present in cardiac surgery.

Simulation can also play a critical role in recruiting medical students into the field. Concern about the contraction of the surgical resident applicant pool and the need for medical students to select a surgical subspecialty at the end of their third year have revitalized recruitment efforts. This need is particularly acute for CT, which has seen the greatest contraction and faces a workforce shortage, intensified by an aging and growing population.^{11,12} The strongest predictor of medical students planning to enter a surgical residency is having the opportunity for hands-on involvement (eg, suturing and driving the camera).^{13,14} CT resident physicians reported that the most influential factor in their career choice was the types of procedures and techniques.¹⁵

Exposure to simulation practice in the preclinical years appears to have promise as a recruitment tool. Half-day programs designed to offer procedural/skill practice to M1 and M2 students have reported increased interest in surgery¹⁶ and in CT surgery.¹⁷ Another approach, which included viewing online material and entirely self-directed practice, resulted in significant pre-to-post improvement on objective and self-assessed measures of general surgical skills.¹⁸ A preclinical elective course, which used a high-fidelity endovascular simulator, demonstrated increased interest in surgical subspecialties and notable pre-to-post skill improvement using objective measures.¹⁹ We also attempted to measure the relationship between skill acquisition and interest in a career in surgery. There was no correlation between actual (rater) skill improvement and a change in interest; however, there was a positive relationship between improvement in self-evaluated score and interest in a career in surgery.

CONCLUSIONS

Our study demonstrated that in teaching a basic CT task, achievement of competency is equal between trainees who are directly supervised and those who have task orientation and available simulators.

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Discussion

Dr Jennifer D. Walker (*Boston, Mass*). Simulation in cardiac surgery covers a broad spectrum of both teaching and learning. There are low-fidelity simulators that repeat tasks and teach basic techniques, as you describe. We have complicated multicomponent tasks that must be learned and also complicated tasks with integrated decision making. The optimal balance is yet to be reached, but I think we all agree that putting more of the responsibility on the learner is more effective.

How do you account for the immediate correction of errors of technique when you're teaching these young learners unsupervised? How do you think the results of this study of first- and second-year medical students will translate to more complex cardiac simulation scenarios?

Dr Enter. Thank you for bringing up these important points. To address your second question first, I think what our study lends itself to is getting the simulator to trainees so that they can be better when they eventually spend time with the staff and they can work on those higher-level skills instead of having to learn early steps of the basic techniques.

And for your first question, by design, we were unable to correct errors of technique in the unsupervised group. This led to our conclusion that it is not supervision—essentially staff correcting mistakes—but rather practice that improves performance.

Dr Walker. How do you see the new curriculum from the Thoracic Surgery Directors Association aiding in this type of cardiac simulation over the next few years?

Dr Enter. I think the unsupervised practice group was largely able to compensate for not being supervised by having multimedia tools available. For instance, we had a video that went through coronary anastomosis that they were able to view. And we collected how many times they viewed it, although it is not displayed here. The efforts of the Joint Council and also the Thoracic Surgery Residents Association to have multimedia materials available so that residents can practice and improve on their own is to our benefit.

Dr Jennifer S. Lawton (*St Louis, Mo*). Tell us about these data. Do you have the data as to how many times they practiced?

Dr Enter. Generally the unsupervised group watched the multimedia a bit more.

Dr Lawton. Those are the students who got better compared with the others who didn't watch the multimedia?

Dr Enter. We didn't look at that.

Dr Dominic Emerson (*Washington, DC*). Great study. There are a lot of data recently coming out of the vascular literature looking at very similar kinds of anastomosis techniques and simulation models, and your data mirror those pretty closely. My question is: How does this apply? There are a number of studies demonstrating improvement at simulating anastomoses, but I don't think I've seen anybody looking at whether this improves performance in the operating room in actual tissue situations. Are you looking at seeing if this applies to any improvement in actual operating skill?

Dr Enter. As for the operating room, they have shown these data in laparoscopic surgery as part of the impetus to develop the fundamentals of laparoscopic surgery curriculum. For vascular anastomoses, work has been done in higher-fidelity models, pig explant models. Maybe you could do a low-fidelity and high-fidelity simulation at the same time. Actually that was part of our initial study. We had everyone do a pig explant model, too. I'd recommend to anyone who attempts this to have a very good video recording system because the on-tissue models it can be much more difficult to visualize and rate on all the different assessment items.

Dr Emerson. You're saying that you think that it is applicable to actual human tissue?

Dr Shari L. Meyerson (*Chicago, Ill*). The thing I find most interesting about this study is that supervised practice seemed to inflate the students' self-evaluation without actually changing their skills. I wonder if you think this points to the ability of faculty to teach effectively and to provide feedback effectively?

Dr Enter. Thank you for bringing up this important point. I believe there are 2 different ways to mentor students. The type that's traditionally done in the operating room is not letting the trainee make a mistake. And my guess is that this is what the supervised practice consisted of. So students thought they were performing well because they were going through it and being corrected in real time. There may be an alternative method of supervision that is afforded by simulation that we didn't demonstrate in this study. Namely where you let trainees make mistakes and learn from them—essentially learning the hard way. That may be what happened in the unsupervised group.

	Poor			Excellent	
1. Arteriotomy	1	2	3	4	5
	Not identify artery Off-midline Multiple "tracks" Injury to back wall Marked irregular edge		Partial artery exposure Mainly midline Thick single "track" Close to back wall Mild irregular edge		Full artery exposure Consistent midline Thin single "track" No injury to back wall Smooth edge
Additional Comments:					
2. Graft orientation	1	2	3	4	5
	Unable to orient Not know start point Not know end point Marked hesitation		Orient with some hesitation Start with some hesitation Knows end point with Some hesitation		Proper heel-toe orientation Consistent start Knows end point No hesitation
Additional Comments:					
3. Bite	1	2	3	4	5
	Irregular entry/exit Hesitant, multiple punctures Inconsistent distance from edge		Mostly regular entry/exit Mostly single puncture Mostly consistent from edge		Consistent regular entry/exit Consistent single puncture Consistent from edge
Additional Comments:					
4. Spacing	1	2	3	4	5
	Uneven/irregular spacing Irregular distance from previous bite		Mostly even spacing Mostly consistent distance from previous bite		Consistent even spacing Consistent distance from previous bite
Additional Comments:					
5. Needle holder use	1	2	3	4	5
	Awkward finger placement Unable to rotate instrument Awkward and not facile Inconsistent needle placement		Functional finger placement Hesitant when rotating Moderate facility Generally good placement		Comfortable, smooth finger placement Smooth rotation High facility Consistent proper placement
Additional Comments:					
6. Use of forceps	1	2	3	4	5
	Awkward or no traction Unable to expose Not use to stabilize needle		Moderate proper traction Able to assist in exposure Able to stabilize but rough		Consistent proper traction Consistent proper exposure Knows when to stabilize, gentle
Additional Comments:					
7. Needle angles	1	2	3	4	5
	Not aware of angles Not compensate for depth Does not consider subsequent angles		Understand angles, not consistent Partial compensation for depth Partial consideration of subsequent angles		Consistent correct angles Compensate for depth Consistent adjustment for subsequent angles
Additional Comments:					

FIGURE E1. The Joint Council on Thoracic Surgery Education (JCTSE) assessment tool. Reprinted with permission from the Joint Council on Thoracic Surgery Education.

8. Needle transfer	1 Marked hesitation in mounting needle	2	3 Able to mount needle with hand and partial manipulation	4	5 Able to mount needle and manipulate needle easily
Additional Comments:					
9. Suture management	1 Not use tension Suture entangled	2	3 Tension use inconsistent Sutures occasionally get in way	4	5 Proper use of tension Suture consistently not in way
Additional Comments:					
10. Knot tying	1 Marked hesitancy, slow speed No follow through Not able to tie, breakage Loose or "air" knot	2	3 Moderate facility, moderate speed intermittent follow through Able to tie and tension, intermittently loose	4	5 Consistent facility, no hesitancy Consistent follow through Consistent tension and tight
Additional Comments:					
11. Hand Mechanics	1 No pronation or supination Awkward finger/hand motion No wrist motion	2	3 Incomplete pronation or supination Hesitant finger/hand motion Incomplete wrist motion	4	5 Able to modulate pronation/supination Smooth, comfortable motion Smooth, appropriate wrist motion
Additional Comments:					
12. Use of both hands	1 Awkward /not coordinated use Non-dominant hand neglect	2	3 Moderately coordinated use Moderate use of non-dominant hand to assist/expose	4	5 Smooth, seamless coordination Full use of non- dominant hand to assist/expose
Additional Comments:					
13. Economy of time and motion	1 Marked hesitation Not aware of goal Unable to do task	2	3 Some hesitation Some awareness of goal Able to do task but discontinuous	4	5 No hesitation Fully aware of goal Able to do task smoothly
Additional Comments:					
Overall	Pass	Fail			
General Definitions:					
5. Excellent, able to accomplish goal without hesitation, showing excellent progress and flow					
4. Good, able to accomplish goal deliberately, with minimal hesitation, showing good progress and flow					
3. Average, able to accomplish goal with hesitation, discontinuous progress and flow					
2. Below average, able to partially accomplish goal with hesitation					
1. Poor, unable to accomplish goal; marked hesitation					

FIGURE E1. Continued.