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Simulation in coronary artery anastomosis early in cardiothoracic surgical residency training: The Boot Camp experience

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Abstract

Objective—We evaluated focused training in coronary artery anastomosis with a porcine heart model and portable task station.

Methods—At "Boot Camp," 33 first-year cardiothoracic surgical residents participated in 4-hour coronary anastomosis sessions (6–7 attending surgeons per group of 8–9 residents). At beginning, midpoint, and session end, anastomosis components were assessed on a 3-point rating scale (1 good, 2 average, 3 below average). Performances were video recorded and reviewed by 3 surgeons in a blinded fashion. Participants completed questionnaires at session end, with follow-up surveys at 6 months.

Results—Ten to 18 end-to-side anastomoses with porcine model and task station were performed. Initial assessments ranged from 2.11 ± 0.58 (forceps use) to 2.44 ± 0.48 (needle angles). Midpoint scores ranged from 1.76 ± 0.63 (forceps use) to 1.91 ± 0.49 (needle angles). Session end scores ranged from 1.29 ± 0.45 (needle holder use) to 1.58 ± 0.50 (needle transfer and suture management and tension; $P < .001$). Video recordings confirmed improved performance

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(interrater reliability > 0.5). All respondents agreed that task station and porcine model were good methods of training. At 6 months, respondents noted that the anastomosis session provided a basis for training; however, only slightly more than half continued to practice outside the operating room.

Conclusions—Four-hour focused training with porcine model and task station resulted in improved ability to perform anastomoses. Boot Camp may be useful in preparing residents for coronary anastomosis in the clinical setting, but emphasis on simulation development and deliberate practice is necessary.

The operating room may no longer be the ideal location for early surgical training because of ethical concerns, time constraints, changes in resident work hours necessitating more structured training, and more complex procedures performed on higher-risk patients.[1–5] In addition, cognitive and technical learning in the operating room provides little opportunity for practice and reflection. Simulation-based learning thus can provide necessary training and practice outside the operating room.

Although simulation and animal laboratory experience have been used extensively in cardiothoracic surgery research and training, it was not until the 1990s that synthetic and mechanical cardiac simulators attracted increased attention. Similar to other surgical specialties, procedures in cardiac surgery can be broken down, allowing the development of partial-task trainers.[1,3,5] After using these basic heart simulators, participants reported more confidence in their ability to perform coronary artery anastomoses.[5–8] Recently, Ramphal and colleagues[8] developed a sophisticated explanted porcine heart model with hemodynamic monitoring for training in a simulated operating room. In addition, Fann and coworkers[5] described the utility in resident training of distributed practice with a simulation of coronary anastomoses. Formal training in using porcine hearts for cardiac surgical training has been organized by a facility in the United Kingdom (WetLab, Ltd, Kenilworth, UK).[9]

The Thoracic Surgery Directors Association and the American Board of Thoracic Surgery organized a “Boot Camp” at the University of North Carolina in August 2008 to provide focused training for approximately a third of all first-year cardiothoracic surgical residents in the United States. According to the principles of simulation-based learning, we proposed that trainees would benefit from such formalized training early in cardiothoracic surgical residency. Five areas were emphasized at the Boot Camp: (1) coronary anastomosis, (2) cardiopulmonary bypass and cannulation, (3) pulmonary resection, (4) bronchoscopy and mediastinoscopy, and (5) aortic valve surgery. For performing coronary artery anastomoses, the porcine heart model with saphenous vein grafts provides a low-technology, high-fidelity (high degree of realism) model, whereas the anastomosis task station provides a low-technology, moderate-fidelity model intended for continued practice in the laboratory and at home. This study evaluated the effect of faculty-supervised focused training in coronary anastomosis with the porcine model and task station.

MATERIALS AND METHODS

Thirty-three first-year cardiothoracic surgical residents, all of whom had completed general surgical residency training, participated in a 2½-day Boot Camp at the Friday Center for

Continuing Education at the University of North Carolina. Residents' previous experience in cardiac surgery was limited to 1 month or less of formal training in adult cardiac surgery. With the 33 residents divided into 4 groups, 4 consecutive hours were devoted to training in coronary anastomosis. Approval was obtained fromthe institutional review board at the University of North Carolina to review and analyze the data.

Simulation Laboratory

The Center was configured to provide an operating area for each resident. Each table was equipped with task lighting, surgical instruments, and polypropylene sutures. Loupe magnification (×2.5) was also provided. For the "wet lab," a porcine heart was positioned in a stand with cryopreserved saphenous vein grafts. Placed at each operating area was a basic anastomosis task station on which was mounted a 4-mm synthetic vessel.

Porcine Heart Model

Explanted pig heartswere prepared and supported in aWetLab Station container. The heart was positioned to expose the left anterior descending artery (Figure 1). The position of the heart replicated conventional sternotomy access, requiring operation at a depth of approximately 3 inches. The porcine model provided the following tasks: exposing the left anterior descending artery, arteriotomy, distal end-to-side anastomosis, and proximal graft-to-aorta anastomosis. Expired cryopreserved saphenous veins (Cryolife, Inc, Kennesaw, Ga) were obtained to use as grafts for the anastomoses, which were performed with 6-0 polypropylene sutures and conventional surgical instruments.

Anastomosis Task Station

The anastomosis task station is a portable apparatus for practicing the technical components of an anastomosis (Figure 2). Mounted on the task station were 4-mm synthetic target vessels; 4-mm synthetic vessels (Chamberlain Group, Great Barrington, Mass) were also used to simulate vein graft for the anastomosis. The anastomoses were performed with 5-0 and 6-0 polypropylene sutures and surgical instruments. Additionally, each resident was given the anastomosis task station to take home to be used for practice.

Study Protocol

Resident performances with the porcine model and task station were evaluated. Thirty-three residents were divided into 4 groups (3 groups with 8 residents and 1 group with 9 residents). There were 6 or 7 faculty members supervising each group of residents. The residents were given a 20-minute lecture on coronary anatomy, angiographic evaluation, and techniques for performing end-to-side coronary anastomoses. The didactic session was followed by each resident performing coronary anastomosis on the porcine model and task station under supervision by a faculty surgeon. After performing arteriotomy of the left anterior descending artery and end-to-side coronary anastomoses with the porcine model, the residents used the task station and performed arteriotomies in the synthetic vessel, followed by end-to-side anastomoses. After the task station, the residents performed additional end-to-side anastomoses with the porcine model.

Performance Assessment

Most residents were directly supervised by a dedicated faculty surgeon during the entire session; formative feedback was given to the resident regarding graft handling and orientation, instrument use, and suture placement. After completion, the anastomoses were inspected and additional feedback given to the resident. This session was analogous to the level of faculty supervision in the operating room. Performance of the anastomosis was evaluated according to a 3-point global rating scale (1 good, 2 average, 3 poor) at the beginning, midpoint, and end of the session (Table 1). Attending surgeons were instructed in the use of the 3-point rating scale, which was modified from the Objective Structured Assessment of Technical Skills (OSATS).[2,5] The components of this rating scale included graft orientation, bites, spacing, use of needle holder, use of forceps, needle angles, needle transfer, and suture management and tension. The rating scale was similar to that previously described for coronary artery anastomosis.[5] Resident performances at the beginning and end of session were recorded with a digital video camera and stored for review. The video data were stripped of identifiers and rated according to the 3-point global rating scale by 3 experienced surgeons in a blinded fashion.

Residents' Rating (Exit Questionnaire)

After completion of the protocol, the participants were asked to complete a questionnaire consisting of 9 statements (see Table 4), for each stating whether they agreed, were not sure, or disagreed. The purpose of the questionnaire was to assess the residents' opinions of the realism of the simulation tasks, the efficacy of the simulator training, and their confidence in performing anastomoses.

Follow-up Survey

The residents were sent a questionnaire 6 months later to assess perceived utility of the Boot Camp. The survey also addressed whether they continued to practice and the availability of simulation-based learning at the training programs.

1. Did the anastomosis session provide a basis for technical training and improvement?
2. Did the synthetic graft-to-graft anastomosis stress important technical components?
3. Did the porcine heart vessel anastomosis stress important technical components?
4. Have your vessel anastomosis skills in the operating room improved in the last 6 months?
5. Have you been able to continue to practice vessel anastomosis out of the operating room?
6. Have you developed your own cardiac surgical simulation devices for practice?
7. Has your residency program started a simulation program in cardiac surgery?
8. From your knowledge of surgical simulation, what is important for simulation in cardiothoracic surgery?

Data Analysis

The data were analyzed with paired *t* tests to compare the global rating scores at beginning, midpoint, and end of session. Paired *t* tests were used for the global rating scores of the subsequent review of video recordings. To assess the interrater reliability when scoring the participants, we used the statistic Savr described by Gaba and coworkers.[10] Savr is a variant of Sav, which is the most generalized form of the *k*-like statistics of interrater agreement referenced to chance. Savr takes into account the ordinal nature of the scale and can accommodate 2 or more raters. For Savr, the by-chance reference is computed on the assumption that raters would have an equal chance of using any of the rating scale elements in rating any particular item and subject.

RESULTS

Technical Skills Assessment

Total number of anastomoses with the porcine heart model and task station varied from 10 to 18. Immediate assessment performed after completion of the session showed improvements in all components. At the beginning, the mean values of components ranged from 2.11 ± 0.58 (for forceps use) to 2.44 ± 0.48 (for needle angles; Table 2). At the midpoint, the scores ranged from 1.76 ± 0.63 (for forceps use) to 1.91 ± 0.49 (for needle angles). The assessments at end of session ranged from 1.29 ± 0.45 (for needle holder use) to 1.58 ± 0.50 (for needle transfer and suture management and tension; $P<.001$ for all comparisons).

Assessment of Video Recordings

Each resident's progress was video recorded at the beginning and end of the anastomosis session. Evaluation of video data confirmed improvement in the anastomosis components (Table 3). Because of the variable degree of assistance and inconsistent viewing angles, graft orientation was difficult to evaluate from the video recordings and therefore was not included in the video review. The interrater reliability of the 3 reviewers for the performance rating scores was greater than 0.5, demonstrating moderate reliability.

Residents' Ratings

Of the 33 participants, 31 completed the initial survey. All residents agreed that the task station and the porcine heart were good methods of training technical skills (Table 4). Although nearly all residents believed that the task station was realistic and that it stressed important components of the anastomosis, only 61%of the residents considered that performing an anastomosis with the task station was realistic. The porcine model was considered realistic and believed to stress important components. All residents were more confident in the ability to perform a coronary anastomosis at the end of the session.

Follow-up Survey at 6 Months

A total of 27 participants responded to the follow-up survey. All agreed that the Boot Camp session provided a basis for technical training and improvement and that the anastomotic task station and the porcine heart model stressed important components. Most (n = 24) believed that their anastomosis skills have improved in the past 6 months (3 qualified their responses, stating that improvement resulted from repetition and mentoring, that additional help or mentoring and supplies were needed, and that cardiac surgery is a second-year rotation and lack of continuity might negate any benefit). Two were unsure whether they had improved because of limited clinical experience (on rotations other than adult cardiac surgery). One reported no improvement (unrelated to Boot Camp). Slightly more than half the respondents (n = 14) continued to practice out of the operating room; however, 5 lacked supplies, time for practice, or ongoing instruction. Thirteen did not practice because of lack of supplies or time (n = 8), reasonable mastery of the skill (n = 4), or sufficient opportunity in the clinical setting (n = 1). Some (n = 10) had developed their own simulation devices. Most (n = 22) reported no local cardiac surgical simulation program; the remaining 5 had wet labs or synthetic model simulations. Finally, the following were considered important in a simulation program: cannulation and cardiopulmonary bypass, coronary anastomosis (on and off pump), valve surgery, thoracic aortic surgery, pulmonary resection, expert mentoring from the beginning, and surgeon-specific descriptions of the procedures for resident review.

DISCUSSION

Consistent with recognized improvement in a workshop approach,[11–14] our findings showed that a focused Boot Camp course improved the ability of the residents to perform coronary anastomoses with the task station and porcine model, as demonstrated by immediate assessment and review of video recordings. Such simulation-based learning early in residency permits residents to interact in a less stressful environment and may be useful in preparing them for the clinical setting; however, emphasis on simulation development and deliberate practice is necessary.

Because the benefit of participating in skills workshop is more profound for junior trainees,[5,12] we focused our efforts at educating first-year cardiothoracic surgical residents early in residency. On the other hand, in a short-term training environment, not all participants necessarily improve.[14] Although the majority of trainees at a microsurgical workshop exhibited an increase in skill level, Atkins and associates[14] found that 27% showed no improvement, demonstrating that attending such a course does not guarantee competency. In the context of training, courses that assess as well as teach a surgical skill are vitally important in identifying individuals requiring skill refinement and remediation. At the Boot Camp, most residents demonstrated marked improvement according to our assessment, whereas a small number had less improvement. Because of the intensive faculty supervision and formative feedback, we believe that focused training allowed the faculty to identify those requiring additional training and provide the necessary feedback to improve their performance.

Previous experience with the training model may not be associated with improved technical skills if the exposure is not repeated.[15,16] Anastakis and coworkers[15] found that residents who underwent simulation training on a procedure in the absence of subsequent reinforcement and in the midst of a large number of live experiences may not have improved ability to perform that same procedure 2 years later. Those residents were not spending their time trying to improve their basic generalizable skills but were concentrating on different procedures each week and thus were unlikely to generate better core surgical skills.[15] Studies in expertise and expert performance indicate that extensive experience and many thousands of hours of deliberate practice are necessary to reach high performance levels.[1,16,17] Deliberate practice involves focus on a defined task and repeated practice, along with coaching and feedback on performance. At the Boot Camp, the residents were taught to perform coronary anastomoses in a supervised fashion, with an emphasis on skill acquisition with the task station and reinforcement with the porcine model. Our intent in this session was not to make the residents experts but rather to teach them techniques that would facilitate their use of instruments, handling of tissues, and proper suture placement. By giving each resident a portable task station and exposing them to the utility of wet labs and the concept of deliberate practice, the intent was to provide them with a basis for further practice after they returned to their respective institutions.

According to the learning principle of massed versus distributed practice in many domains, distributed practice (or practice interspersed with rest) leads to better skill acquisition and retention.[5,11,18] Task performance often has been measured immediately after the end of the practice sessions (acquisition performance), however, and there has been inconsistent examination of retention performance.[8] Other factors, such as the type of task being practiced, amount of time between practice sessions, participant motivation, and activity during the intertrial interval, also may impact the effect of distributed practice.[18] For instance, stronger effects were found for simple tasks when using very brief rest periods; for more complex tasks, longer rest periods appeared to be more beneficial for task learning. In this study, a small vessel anastomosis can be considered to be of moderate difficulty, and relatively brief periods of rest may be sufficient. Although the Boot Camp approach was predicated on a massed practice model, with its limitations relative to distributed practice, the intent was to provide these highly motivated residents sufficient time to acquire the basic skills necessary for performing coronary anastomoses. The need for distributed practice to optimize skill retention and improvement was discussed, and the basic task station can potentially be used as part of such practice.

In studies on model fidelity and educational effectiveness, a low-fidelity bench model conferred the same degree of benefit as training on a high-fidelity model for certain procedures.[13,19] Because skills acquired on low-fidelity bench models transfer to improved performance with higher-fidelity models, some have suggested that such simulation may transfer into the operating room.[3,20–22] For surgical educators intending to incorporate lab-based surgical skills training into the curriculum, a reasonable strategy would be to begin by having novice trainees learn on a low-fidelity bench model that captures the key constructs of the surgical task. Once proficient, the trainee can then progress in a graduated manner to practice on models of higher fidelity.[13] For vascular anastomosis, however, there may be better skill transfer from the bench model to live animals when practicing on high-fidelity models, consistent with the concept that the closer the practice conditions are to real-life conditions, the better the learning.[23] One possible explanation for the discrepancy between this concept and the results of previous studies is that novice participants are often taught the task, and it may be that the high-fidelity models provide additional contextual information about the task that the novices are not prepared to use in their training.[13,23] Another possibility is that for novices there is a large amount of learning just from the ability to practice techniques on any type of model, in which case the level of model fidelity may have a lesser impact than for more experienced operators.[23] Thus having appropriate model fidelity for trainees of different abilities may optimize the effectiveness of bench model training. At the Boot Camp, we used both a moderate-fidelity task station to emphasize the technical components of coronary anastomosis and a high-fidelity porcine model to provide greater realism as the trainee became more technically proficient. In curriculum development, technical simulators of varying fidelity would be important for such differentiated learning as the resident progresses in training.

Depending on the extent of previous training and surgical experience, which may vary greatly in current training programs, residents at the same training level may be at different proficiency levels, and simulation-based learning is a means of assessing proficiency. One fundamental assessment tool is the OSATS, which includes a task-specific checklist and a global rating scale.[1,2,24] The global rating is more accurate and reliable than checklists, particularly in assessing advanced simulations or operations.[3,11,24] Although resident assessment is routinely undertaken by attending surgeons, most have no formal training in skills assessment and may not use objective methodology.[3] The global rating scale in this study was therefore adapted to reflect the background of the participating surgeons in providing performance assessments. Because of the number of faculty members at the Boot Camp and their variable experience with assessment tools, the rating scale was modified to a 3-point scale. Additionally, in a previous evaluation of cardiothoracic surgical residents who had completed general surgical residency training, global rating scores for anastomosis tended to cluster on the more competent end of a 5-point scale.[5] We therefore posited that a 3-point global rating scale would adequately assess resident performance in this study. In addition to immediate performance assessment, subsequent assessment from review of video data has been shown to be reliable in the laboratory and operating room settings.[3,11] Potential biases in the initial assessment were mitigated by retrospective review of video recordings. Video recordings may be limited by technical problems, however, or may not accurately record teacher–trainee interactions.[25] At the Boot Camp, even in light of potential limitations, such an assessment demonstrated improved performance according to the global rating scale after 4 hours of focused training.

Finally, the follow-up survey provided information with respect to the medium-term impact of the Boot Camp. The Boot Camp was perceived as effective in skill acquisition; however, distributed and deliberate practice were not universally used. Future Boot Camp experiences will need to emphasize the need for practice outside the operating room and to arrange for supplies at the local institutions. Our specialty is currently in transition with regard to simulation-based learning in residency training, and a concerted effort is underway to encourage the use of simulation. Similar to general surgical simulation programs,[1,5,11,15] cardiac surgical simulation should focus on the importance of deliberate practice, distributed practice, and model fidelity.

LIMITATIONS

One important limitation is that simulators do not reproduce the tissue responses seen in human pathology. The porcine coronary artery, although realistic, is without disease, and

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such models are thus deficient in this regard. Another limitation is that the Boot Camp training was 4 hours of massed practice with no assessment of skill retention; these findings are therefore considered preliminary, and more complete assessment is necessary. The rating scale in this study may be less comprehensive than scales previously described and may not detect all the important features of the task. We incorporated the main principles of the global rating scale of OSATS and propose that our rating scale is able to assess most of the important components of coronary anastomosis. Not only should assessment scales be customized to the task, they must be user friendly and adapted to the experience of the assessors. As the assessors become more experienced and better anchored, interrater reliability is likely to increase. The issue of whether the improved performance at the Boot Camp would be transferable to the operating room was not addressed in this study, and further follow-up evaluations will be necessary. Performance within the operating room depends not only on technical skill but also on cognitive integration, judgment, and complex interactions among team members.

In conclusion, focused training at the Boot Camp significantly improved the ability of residents to perform coronary anastomoses with the task station and porcine model. The intent was not to make these residents experts but rather to teach techniques that would facilitate performing coronary anastomosis. Because of the intensive faculty supervision and formative feedback, we believe that focused training allowed the faculty to identify those requiring additional training and provide the necessary feedback to improve their performance. The Boot Camp is but one method of augmenting early resident training, and the need for a structured curriculum for simulation-based learning is well recognized. To optimize skill retention, the concept of distributed and deliberate practice will continue to be emphasized at subsequent Boot Camps and to the surgical educators as they develop skills laboratories and a simulation curriculum.

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Abbreviation and Acronym

OSATS	Objective Structured Assessment of Technical-Skills

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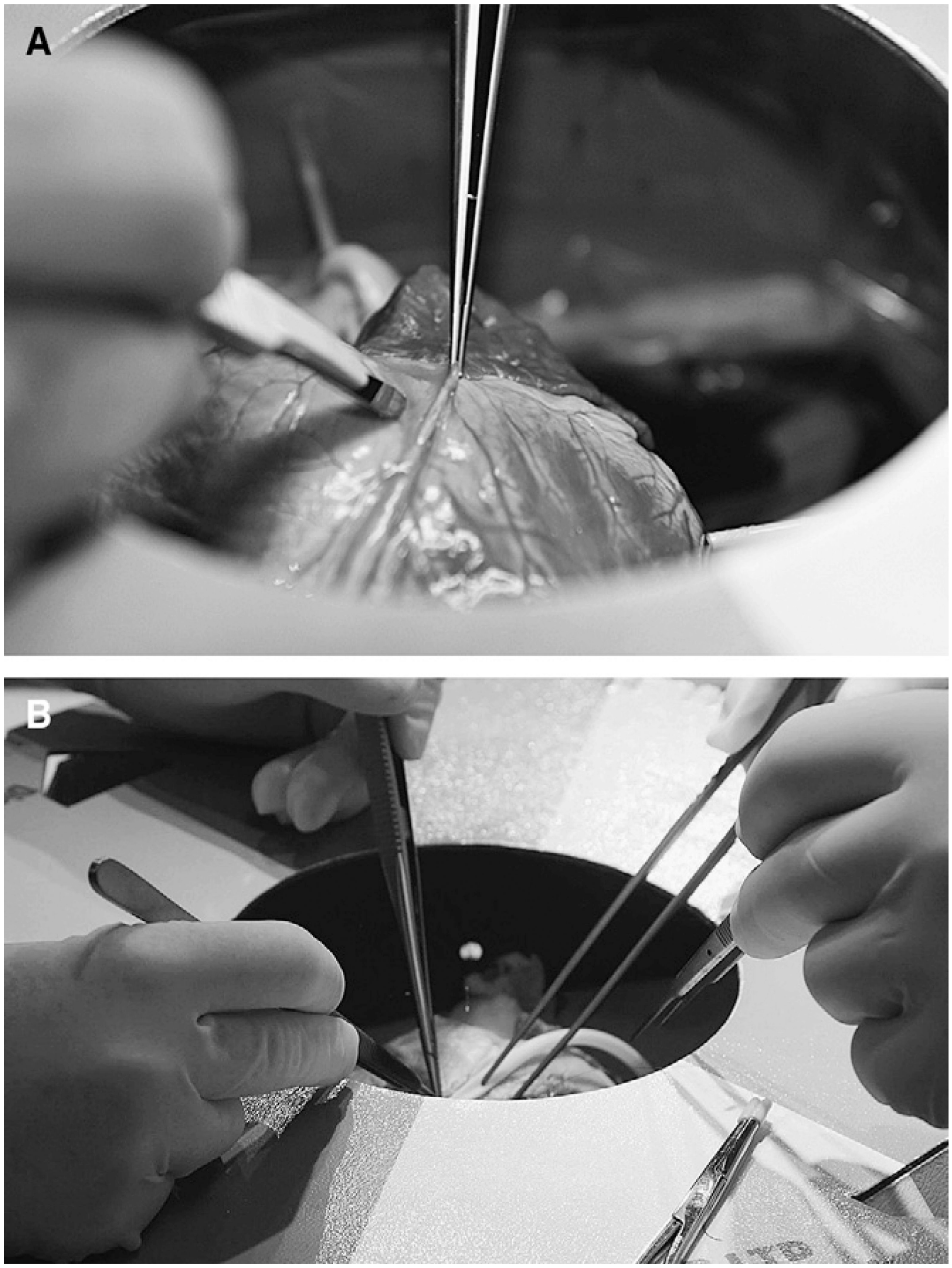

FIGURE 1.

Porcine heart is situated in wet lab container, with access to left anterior descending artery and ascending aorta.

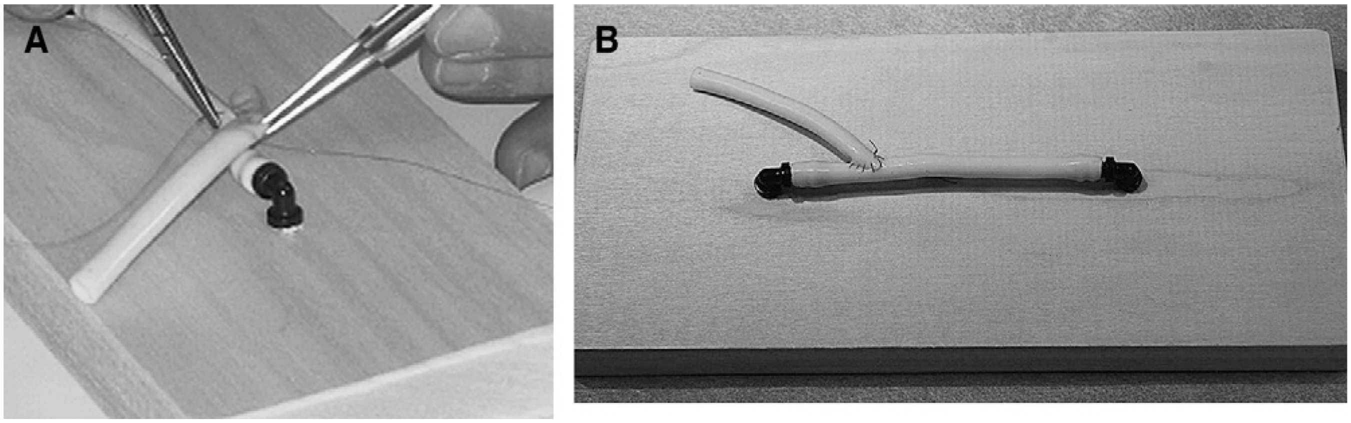

FIGURE 2.
Portable anastomosis task station with synthetic target vessel permits multiple end-to-side anastomoses with synthetic graft.

TABLE 1

Components of global rating scale for assessment of coronary anastomosis

	Good	Average	Poor
Graft orientation	1	2	3
(proper orientation for toe–heel, appropriate start and end points)			
Bite appropriate	1	2	3
(entry and exit points, number of punctures, even and consistent distance from edge)			
Spacing appropriate	1	2	3
(even spacing, consistent distance from previous bite, too close vs too far)			
Use of Castroviejo needle holder	1	2	3
(finger placement, instrument rotation, facility, needle placement, pronation and supination)			
Use of forceps	1	2	3
(facility, hand motion, assist needle placement, appropriate traction on tissue)			
Needle angles	1	2	3
(proper angle relative to tissue and needle holder, consider depth of field, anticipating subsequent angles)			
Needle transfer	1	2	3
(needle placement and preparation from stitch to stitch, use of instrument and hand to mount needle)			
Suture management and tension	1	2	3
(too loose vs tight, use tension to assist exposure, avoid entanglement)			

Good, Able to accomplish goal without hesitation, showing excellent progress and flow; *Average*, able to accomplish goal with hesitation, discontinuous progress and flow; *Poor*, able to partially accomplish goal with hesitation. Adapted from Objective Structured Assessment of Technical Skill (OSATS).[2]

TABLE 2

Mean performance rating scores based on immediate assessment

	Beginning	Midpoint	End
Graft orientation	2.30 ± 0.50	1.86 ± 0.46	1.36 ± 0.47
Bite appropriate	2.29 ± 0.56	1.77 ± 0.50	1.36 ± 0.47
Spacing appropriate	2.33 ± 0.51	1.89 ± 0.45	1.35 ± 0.46
Needle holder use	2.20 ± 0.67	1.80 ± 0.51	1.29 ± 0.45
Use of forceps	2.11 ± 0.58	1.76 ± 0.63	1.50 ± 0.56
Needle angles	2.44 ± 0.48	1.91 ± 0.49	1.42 ± 0.49
Needle transfer	2.24 ± 0.49	1.89 ± 0.50	1.58 ± 0.50
Suture management and tension	2.33 ± 0.62	1.88 ± 0.52	1.58 ± 0.50

Data are expressed as mean ± SD. Paired *t* test was performed for beginning versus midpoint, beginning versus end, and midpoint versus end. For all comparisons, $P < .001$; with Bonferroni correction, $P < .016$ for significance.

TABLE 3

Mean performance rating scores according to subsequent review of the video recordings

	Beginning	End
Graft orientation*	—	—
Bite appropriate	2.15 ± 0.43	1.61 ± 0.56
Spacing appropriate	2.13 ± 0.52	1.62 ± 0.58
Needle holder use	2.19 ± 0.52	1.60 ± 0.56
Use of forceps	2.10 ± 0.55	1.57 ± 0.52
Needle angles	2.12 ± 0.45	1.46 ± 0.54
Needle transfer	2.09 ± 0.57	1.58 ± 0.59
Suture management and tension	2.11 ± 0.49	1.56 ± 0.55

Data are expressed as mean ± SD. Comparisons by paired *t* test; $P < .001$ for all comparisons except graft orientation.

*Unable to assess, see text.

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TABLE 4

Exit questionnaire (n = 31 respondents)

Statement	Agree	Not sure	Disagree
The task station synthetic vessel anastomosis was realistic.	29 (94%)	2(6%)	
The task station synthetic vessel anastomosis stressed important components.	30 (97%)	1(3%)	
Performing an anastomosis on the task station was realistic.	19 (61%)	9 (29%)	3 (10%)
The wet lab (porcine heart) anastomosis was realistic.	31 (100%)		
The porcine heart anastomosis stressed important components.	31 (100%)		
Performing an anastomosis on the porcine heart was realistic.	31 (100%)		
The task station is a good method of training technical skills.	31 (100%)		
The porcine heart is a good method of training technical skills.	31 (100%)		
I am more confident in coronary anastomosis.	31 (100%)		