Simulation-Based Training in Cardiac Surgery

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Background. **Operating room surgical training has significant limitations. This study hypothesized that some skills could be learned efficiently and safely by using simulation with component task training, deliberate practice, progressive complexity, and experienced coaching to produce safer cardiac surgeons.**

Methods. **Training modules included cardiopulmonary bypass, coronary artery bypass grafting, aortic valve replacement, massive air embolism, acute intraoperative aortic dissection, and sudden deterioration in cardiac function. Using deliberate practice, first-year cardiothoracic surgical residents at eight institutions were trained and evaluated on component tasks for each module and later on full cardiac operations. Evaluations were based on five-point Likert-scale tools indexed by module, session, task items, and repetitions. Statistical analyses relied on generalized linear model estimation and corresponding confidence intervals.**

Results. **The 27 residents who participated demonstrated improvement with practice repetitions resulting in excellent final scores per module (mean ± two SEs): cardiopulmonary bypass, 4.80 ± 0.12; coronary artery bypass grafting, 4.41 ± 0.19; aortic valve replacement, 4.51 ± 0.20; massive air embolism, 0.68 ± 0.14; acute intraoperative aortic dissection, 4.52 ± 0.17; and sudden deterioration in cardiac function, 4.76 ± 0.16. The transient detrimental effect of time away from training was also evident.**

Conclusions. **Overall performance in component tasks and complete cardiac surgical procedures improved during simulation-based training. Simulation-based training imparts skill sets for management of adverse events and can help produce safer surgeons.**

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For most surgical training, technical skills are taught by the apprentice model: resident physicians learn under supervision in the operating room, by performing portions of or complete real operations on real patients. Many highly competent surgeons have been trained in this manner. Today, however, apprentice teaching in the operating room provides insufficient time to teach technical skills, has low tolerance for learning inefficiency, eliminates deliberate practice, and does not ensure exposure to rare but important adverse events. All these elements are essential to producing safe surgeons.

Motivated by efforts to improve patient safety and with the introduction of a high-fidelity cardiac surgical simulator by Ramphal and colleagues [1], we evaluated the feasibility of accomplishing significant elements of cardiac surgical training efficiently and more safely outside the operating room by using innovative simulation technology in a rigorous curriculum.

Material and Methods

Surgeons from eight thoracic surgical residency programs with experience in simulation-based learning—the University of North Carolina at Chapel Hill, Chapel Hill,

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Abbreviations and Acronyms

AIAD	= acute intraoperative aortic dissection
AVR	= aortic valve replacement
CABG	= coronary artery bypass grafting
CPB	= cardiopulmonary bypass
MAE	= massive air embolism
SDCF	= sudden deterioration in cardiac function
UNC	= University of North Carolina at Chapel Hill

North Carolina (UNC); Johns Hopkins University, Baltimore, Maryland; Massachusetts General Hospital, Boston, Massachusetts; Mayo Clinic, Rochester, Minnesota; Stanford University, Stanford, California; University of Rochester, Rochester, New York, University of Washington, Seattle, Washington; and Vanderbilt University, Nashville, Tennessee—formed the Cardiac Surgery Simulation Consortium. Under Agency for Healthcare Research and Quality grant R18HS020451, the consortium created a 39-session curriculum to investigate whether simulation-based learning in cardiac surgery could enhance resident training, thereby contributing to the safety of surgical patients.

Each center agreed to use the curriculum to train two first-year cardiothoracic surgical residents (first-year residents for traditional 2- or 3-year residency programs, or fourth-year or fifth-year residents for 6-year integrated residency programs) in each of 2 consecutive years, for a total of four residents per institution. The Institutional Review Boards at UNC and five other institutions determined that the study was exempt from further review because it was conducted in an educational setting; two Institutional Review Boards (Johns Hopkins University and University of Washington) required participating residents to sign consent forms. Resident data were de-identified for analysis. No live animals were used, and no animals were harmed for this study.

Curriculum

Training used principles of component task training as described by Sullivan and associates [2] and deliberate practice with multiple coached and observed repetitions as described by Ericsson and colleagues [3]. The consortium created training modules for three commonly performed cardiac surgical procedures—cardiopulmonary bypass (CPB), coronary artery bypass grafting (CABG), and aortic valve replacement (AVR)—and for three adverse intraoperative events—massive air embolism (MAE), acute intraoperative aortic dissection (AIAD), and sudden deterioration in cardiac function (SDCF). Consortium members determined by consensus the modules and their major component tasks, training methodology, objectives and goals, and assessment tools for each session.

Each institution used its own techniques during training (eg, type of cannulas, number of pursestring sutures, or how the aorta was closed). The consortium designed specific task simulators for component tasks. Each module included five to seven training sessions at least a week apart. Procedures learned in earlier modules were used and evaluated in later modules. For example, performance of CPB, CABG, and AVR were all used in MAE, AIAD, and SDCF.

Initial sessions in each module focused on individual component tasks, whereas subsequent sessions combined multiple component tasks representing whole procedures. Similarly, early modules provided the basis for adverse-event training in subsequent modules (Table 1).

Investigators used 21 assessment tools to evaluate performance on tasks, procedures, and component subprocedures. Assessment tools for vessel anastomosis were from the Thoracic Surgery Directors Association and the Joint Council for Thoracic Surgery Education's assessment committee [4]. The investigators created the other 19 assessment tools based on modifications of the Objective Structured Assessment of Technical Skills (OSATS) model with a five-point anchored Likert scale [5].

Each task-specific assessment tool included numerous Likert items that addressed performance on specific skills. For example, the aortic valve replacement assessment tool (AVRAT) evaluated seven Likert items such as "root setup," "valve excision," and "suture placement" (Table 1). As complexity and breadth of simulations increased, component tasks from earlier sessions were represented as single Likert items (instead of multiple-item Likert scores) in the overall procedure. For example, for the component task of venous cannulation in the early part of the CPB module, Likert items in the venous cannulation assessment form were basic skills, such as "needle angle," "spacing," or "needle holder use." During the final three sessions of complete CPB, the ability to place the venous cannula was evaluated as a single Likert item (venous cannulation) in the overall cardiopulmonary bypass assessment tool (CPBAT).

Video recordings of sessions were collected and archived. They were not intended to be part of the formal analyses in this report.

For each session, the curriculum specified goals and objectives, equipment and supplies, conduct of the simulation, and assessment tools. Each session was coached by an attending cardiothoracic surgeon with assistance from a simulation technician and lasted 3 to 4 hours. Sessions were performed in sequence and on a weekly schedule as much as possible, given other responsibilities of residents and coaches. The coaches administered assessment tools to evaluate the residents.

The consortium met frequently to monitor the study. At the end of the first year, the consortium reevaluated the curriculum and made changes to improve efficiency and teaching efficacy. For example, repetitions were reduced, and timing of one activity was shifted from one session to another. These changes were expected to have a negligible effect on the comparability of first-year and second-year data. In some centers, completion of the first year of training ran into the second academic year. In those cases, the residents from both years underwent contemporaneous training but followed their year-specific curricula.

Table 1. Cardiac Surgery Simulation Curriculum

Module	CPB	CABG	AVR	MAE	AIAD	SDCF
Session 1	Fundamentals of CPB	Proximal anastomosis-synthetic	Dissection of heart for aortic valve anatomy	MAE-EAP creation	AIAD-EAP creation	Crash back on bypass
Session 2	Aortic cannulation	Distal end to side-synthetic	Aortotomy and closure of the aorta	Walk through of MAE-EAP	Femoral arterial cannulation	Failure to wean
Session 3	Venous cannulation	Distal (LAD) CryoVein (CryoLife, Inc, Kennesaw, GA) porcine heart	Valve excision and annular suture placement	Retrograde perfusion and removal of air on Ramphal simulator	Repair of acute aortic dissection	Issues with CABG: static model
Session 4	Cardioplegia	Distal (eg, LAD, OM, PDA) with CryoVein/porcine heart	Valve ring sutures, valve seating and tying	MAE-EAP performance on Ramphal simulator	AIAD-EAP performance on Ramphal simulator	Issues with CABG: Ramphal simulator
Session 5	Full CPB on Ramphal simulator	Full CABG on Ramphal simulator	Removal of air from the heart	MAE-EAP performance on Ramphal simulator	AIAD-EAP performance on Ramphal simulator	Issues with prosthetic valves
Session 6	Full CPB on Ramphal simulator	Full CABG on Ramphal simulator	Full AVR on Ramphal simulator			Final examinations: SDCF
Session 7	Full CPB on Ramphal simulator	Full CABG on Ramphal simulator	Full AVR on Ramphal simulator			Final examinations: SDCF
Session 8			Full AVR on Ramphal simulator			

AIAD = acute intraoperative aortic dissection; AVR = aortic valve replacement; CABG = coronary artery bypass grafting; CPB = cardiopulmonary bypass; EAP = emergency action plan; LAD = left anterior descending artery; MAE = massive air embolism; OM = obtuse marginal branch of circumflex coronary artery; PDA = posterior descending branch of right coronary artery; SDCF = sudden deterioration in cardiac function.

Component task simulators were created and supplied by UNC or were purchased commercially when available. Before the study started, the eight institutions bought Ramphal cardiac surgery simulators built at the University of the West Indies–Mona, Kingston, Jamaica (Fig 1). Porcine hearts for the Ramphal simulators were prepared and supplied by UNC. All tissues used in the study were waste products obtained from commercial food suppliers. A commercial version of the Ramphal simulator and the prepared hearts are now available through a licensing agreement with the University of the West Indies–Mona (KindHeart, Inc, Chapel Hill, NC.) Teleflex, Inc (Morrisville, NC) donated surgical instruments and sutures for the study to each institution; CryoLife, Inc (Kennesaw, GA) donated CryoVein saphenous vein.

Database Management

During the study, data for each resident accrued as hundreds of "Likert items." These data were recorded on paper forms (assessment tools), transcribed to spreadsheet files, and transmitted to coordinating personnel at UNC for the database. The Likert-item data were indexed by site, academic year, module, session, assessment tool identification, participating resident's study identification, repetition number, date of session, and instructor-evaluator's study identification. Data were retrieved from site-specific spreadsheet files into a composite spreadsheet file. The curriculum and the composite spreadsheet were used to build a unified SAS (SAS Institute, Inc, Cary, NC) dataset file that was subsequently edited to correct documented inconsistencies and anomalies. For a few occurrences of missing data, archived video recordings were reviewed by the sites' principal investigators to provide surrogate Likert-item values.

Statistical Analysis Strategy

For a given assessment tool (in a given module, session, and repetition), the task-specific Likert items were summed and then divided by the number of Likert items to obtain the "Likert score." In cases of incomplete data, the missing Likert items were assumed to be ignorably missing (caused by mechanisms that satisfy the missing-completely-at-random criteria), and the Likert score was computed as the mean of the nonmissing Likert items.

The primary analyses relied on estimation of means, medians, and modes, together with appropriate confidence intervals, for Likert scores and Likert items. Careful consideration was given to potential problems that could arise in application of these methods to the ordinal Likert items. The point estimates and confidence intervals were obtained by linear model estimation using generalized estimating equation (GEE) methods. A compound-symmetry working correlation matrix was assumed to account for high-dimensional multilevel nesting and clustered nature of the data. Under mild assumptions, estimates obtained by this approach are unbiased.

Using these methods, two complementary forms of analysis were performed: A "per-repetition" analysis and a "per-session" analysis. The per-repetition analysis provided estimates of mean response as a function of the number of times the participant had practiced a task, regardless of when that practice occurred during the curriculum. In contrast, the per-session analysis provided assessment tool–specific estimates of mean response for each occasion of evaluation (ie, for each scheduled evaluation within each session or for each session within each module). This per-session approach also served to summarize the number of occurrences of missing values for each occasion.

Auxiliary sensitivity analyses were performed to evaluate the robustness of the primary results to reasonable perturbations of statistical methods and assumptions used. These analyses included variations in the definition of the response variable. For example, we considered analyses in which the Likert outcome was replaced by (1) a binary variable indicating whether the participant earned a perfect score on the entire assessment tool or (2) a binary variable indicating whether the participant

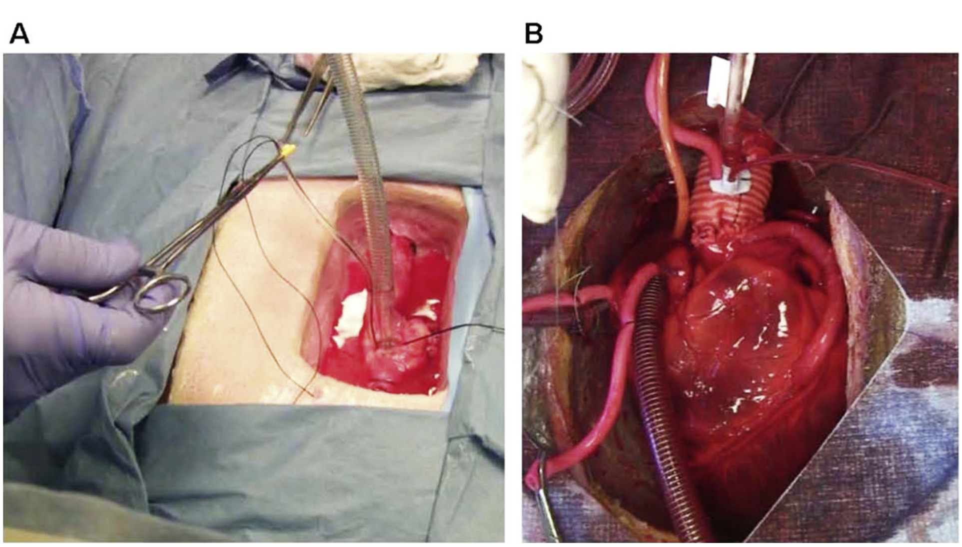

Fig 1. (A) Component task simulator allowing for deliberate practice and multiple repetitions of ascending aortic cannulation, removal of air from the aortic line, and decannulation. (B) Completed repair of ascending aortic dissection occurring during coronary artery bypass in the acute intraoperative aortic dissection module using the Ramphal cardiac surgery simulator.

earned a perfect score on the Likert item within the assessment tool.

All statistical computations were performed using SAS software (Version 9.4).

Results

Twenty-seven residents participated in the curriculum, with instruction, coaching, and evaluations provided by 18 faculty members. The 39 sessions were planned to occur weekly, but they took longer to complete at most institutions because of residents' clinical responsibilities, vacation schedules, or "away" rotations. Institutions that insisted on protected time for residents' training were much more efficient in completing the curriculum on time.

Five institutions each contributed four residents to the study; two had three residents each, and one institution had one resident. The lower numbers related to institutions' conversion to the Integrated-6 residency training paradigm or to an unanticipated vacancy in the residency program. All residents who started the curriculum finished, but completeness of data reflecting residents' participation was variable. Likert item data entered per resident ranged from 192 to 968 values, with a median of 710 values per resident out of a maximum possible 1,200 values. The 27 participants produced 18,952 Likert item scores out of a possible 27,108 (70%). The six modules contributed nonmissing Likert items as follows: CPB, 5,109; CABG, 4,756; AVR, 3,005; MAE, 1,422; AIAD, 1,058; and SDCF, 3,602 items.

The per-repetition analyses showed a clear relationship between repetition of a task and improvement in performance. An example is shown in Figure 2, for the component task of aortic cannulation. As seen in the upper panel, residents performed repetitions of only aortic cannulation on the aortic cannulation component task simulator during a single session. Likert scores increased from 3.38 to 4.74. In the lower panel, aortic cannulation performance is measured as part of complete procedures (CPB, CABG, AVR, SDCF). These modules occurred sequentially in the curriculum; thus, SDCF was performed at least 18 weeks after CPB. The data show improvement from a Likert score of 3.63 to 4.78 for residents completing the highest number of repetitions. Interestingly, the aortic cannulation score dropped when the procedure was initially performed as part of a more complex, multiple-component task procedure (eg, as part of CABG). Performance recovered and improved further with repetition of the complete procedure.

These results were observed with most component tasks. Comparable per-session results (Fig 3) show this temporal improvement trajectory as a function of the increasing number of evaluations for each of five component tasks within the AVR module (ACAT, AVRAT, DAAT, VCAF).

Figure 3 also indicates a transient decline from the end of one session to the beginning of the next session, with subsequent recovery and even further improvement. All component tasks were performed and sustained at a very high level as part of the complete procedure of AVR. These results were observed with all complete procedures. Progression to high levels of performance was also seen in the three adverse-event modules. As an example, aortic repair was taught as an isolated component task in session 3 of the AIAD, and it showed an improvement in mean Likert score from 4.09 to 4.56 with repetitions. Similar improvement occurred in the component task of femoral cannulation. The component task training allowed the resident to handle the rare adverse event of AIAD (Fig 4). By the final session of every module, at least 95% of the residents received nearly perfect or perfect scores (4 or 5 on the Likert scale, data not shown) (Table 2).

Comment

With more than 3,000 hours of training, this was a large, comprehensive study of simulation-based training in cardiothoracic surgery. Our intent was not to show that simulation-based training could replace clinical training. It was to determine whether a simulation-based curriculum could enhance and facilitate training by circumventing the educational limitations of the operating room.

A clearly defined, detailed curriculum was essential to the training's success, and with close communication among investigators, it resulted in a reasonably high level of compliance and uniformity.

Two key components were component task training [2] and deliberate practice [3], both of which are unavailable in the clinical operating room. It is curious that almost all endeavors that require mastery of a skill (eg, music or sports) rely on these methods, and yet surgery has not incorporated them. Although the modern operating room cannot accommodate many of the basic principles of education, our study shows that simulation-based training can; it resulted in improvement in all surgical skills evaluated in this study.

Studies have shown transferability of surgical skills and behavior from the simulation laboratory to the clinical setting. A review of the effect of simulation-based training on clinical performance in laparoscopic surgery in 20 randomized control trials found evidence of improved clinical performance in surgeons who underwent simulation-based training [6]. A clinically significant decrease in catheter-related bloodstream infections followed simulation-based education for medical intensive care residents, and this education is now mandatory in most teaching institutions [7]. A review of 27 randomized clinical trials and seven nonrandomized comparative studies of laparoscopy and endoscopy provided "strong evidence that participants who reached proficiency in simulation-based training performed better in the patient-based setting than their counterparts who did not have simulation-based training" [8].

On the assumption that training improves surgical skills, decision making, and communication during adverse events, we dedicated a major part of the curriculum to patient safety, with three adverse-event modules (MAE, AIAD, and SDCF). Only the simulated environment can provide the means for orchestrating each

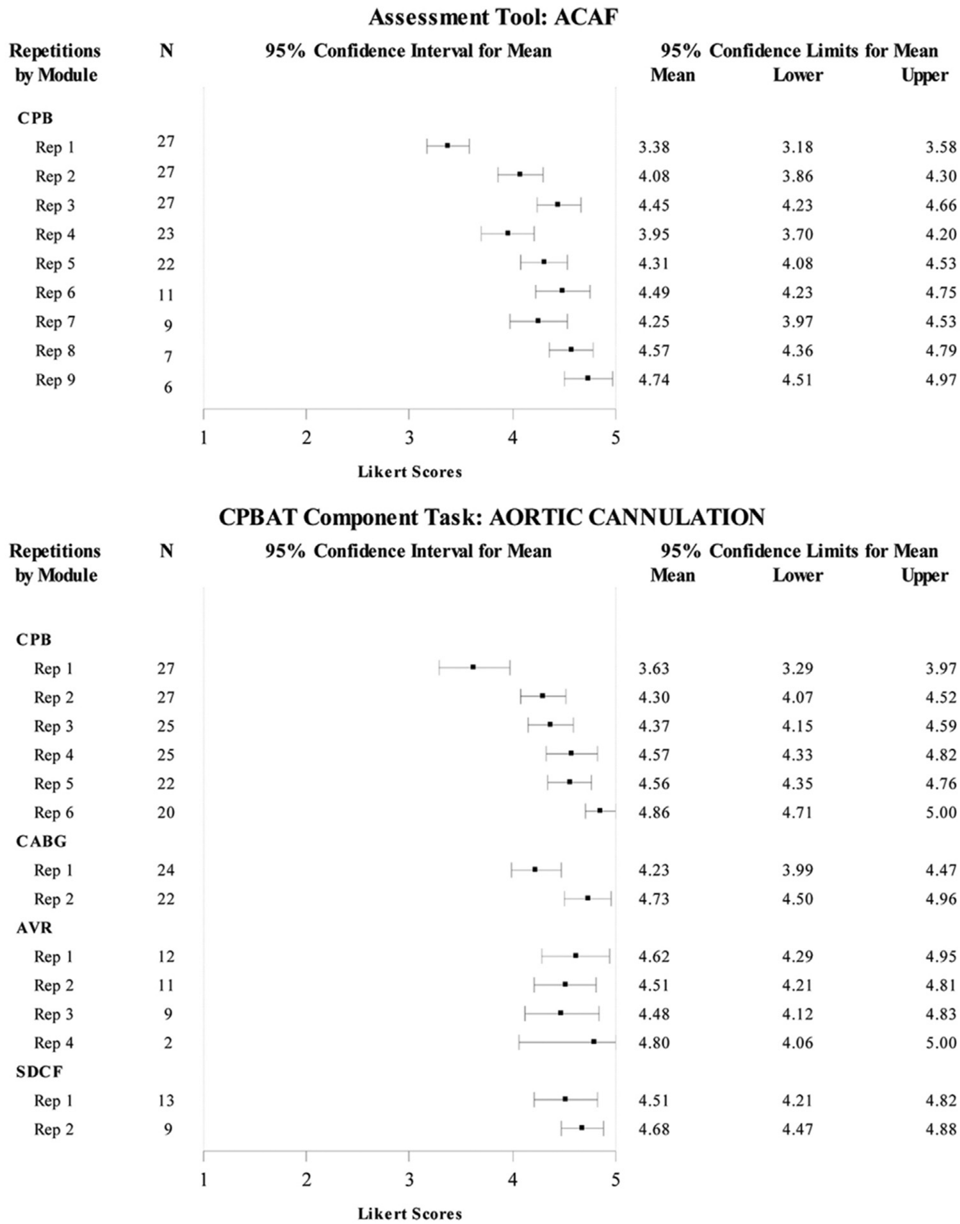

Fig 2. For aortic cannulation assessment form (ACAF) scores, the upper panel shows the statistical estimate of the mean for each repetition the residents performed during various sessions of the cardiopulmonary bypass (CPB) module. The bottom panel summarizes performance per repetition based on the aortic cannulation Likert item evaluated in four different modules. (AVR = aortic valve replacement; CABG = coronary artery bypass graft; CPBAT = cardiopulmonary bypass assessment tool; SDCF = sudden deterioration in cardiac function.)

complete clinical situation (event onset, management, resolution) while placing the trainee as the responsible lead clinician. Parts of the curriculum could help in certification and hospital credentialing.

Repetition, training, instruction, and practice were used in each module and resulted in a significant improvement in surgical skills, communication, and decision making.

In a companion analysis of our study by Mokadam and associates [9], a questionnaire was sent to all participating residents and faculty after training ended. In their responses, residents and faculty perceived significant benefits from this training transferred to the operating room, including more confidence, faculty's greater comfort level with the resident, and improved initial surgical skills. These findings were especially evident in institutions where clinically active faculty members were simulation coaches.

The cost of simulation-based training is a concern, especially when it must be borne by the residency program. The task simulators used in the study are inexpensive and easy to build, and they represented approximately 50% of the training. Expired or clinically antiquated clinical supplies were used when available. The Ramphal simulator provided a platform for very high-fidelity cardiac surgical simulation and allowed for the integration of the component tasks for each module in a clinically meaningful way. It does, however, require more of a financial investment. We also found that a

Module: AVR

Procedure by Assessment Tool	N	Mean	Lower	Upper
1. ACAT				
Session 1: Evaluation 1	16	3.78	3.58	3.99
Session 1: Evaluation 2	13	4.35	4.21	4.50
Session 2: Evaluation 3	23	4.17	3.96	4.38
Session 2: Evaluation 4	20	4.43	4.29	4.57
Session 5: Evaluation 5	9	4.47	4.21	4.74
Session 5: Evaluation 6	2	4.59	4.08	5.00
2. AVRAT				
Session 2: Evaluation 1	9	3.89	3.57	4.22
Session 2: Evaluation 2	9	4.41	4.17	4.65
Session 3: Evaluation 3	17	4.09	3.90	4.28
Session 3: Evaluation 4	15	4.56	4.41	4.71
Session 4: Evaluation 5	14	4.36	4.14	4.58
Session 4: Evaluation 6	12	4.54	4.37	4.71
Session 5: Evaluation 7	9	4.36	4.02	4.70
Session 5: Evaluation 8	2	4.38	4.17	4.59
Session 6: Evaluation 9	14	4.61	4.43	4.79
3. DAAT				
Session 4: Evaluation 1	9	3.88	3.57	4.19
Session 4: Evaluation 2	9	4.09	3.87	4.32
Session 4: Evaluation 3	9	4.38	4.11	4.65
Session 5: Evaluation 4	13	4.29	4.08	4.50
Session 5: Evaluation 5	9	4.46	4.19	4.72
Session 5: Evaluation 6	9	4.82	4.63	5.00
4. PAT				
Session 1: Evaluation 1	11	4.70	4.47	4.94
5. VCAF				
Session 5: Evaluation 1	9	4.80	4.59	5.00
Session 5: Evaluation 2	2	4.95	4.59	5.00
6. COMPLETE AVR				
Session 6: Evaluation 1	10	4.36	4.13	4.59
AVRAT	9	4.35	4.10	4.59
DAAT	9	4.29	4.02	4.56
Session 7: Evaluation 2	25	4.56	4.43	4.70
AVRAT	25	4.56	4.42	4.70
DAAT	13	4.55	4.40	4.70
Session 8: Evaluation 3	15	4.51	4.31	4.71
AVRAT	15	4.53	4.34	4.73

(Mean, Lower and Upper: 95% Confidence Limits for Mean)

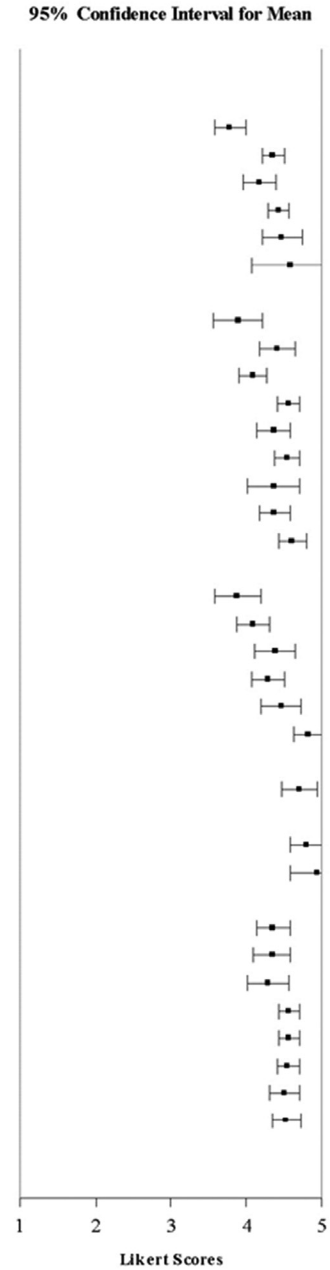

Fig 3. For each assessment tool in the aortic valve replacement (AVR) module, the statistical estimate of the mean is shown for each evaluation of the residents. Data show improvement in component task performance with repetitions sustained in the performance of the complete aortic valve replacement procedure. (ACAT = aortic closure assessment tool; AVRAT = aortic valve replacement assessment tool; DAAT = deairing assessment tool; PAT = prosection assessment tool; VCAF = venous cannulation assessment form.)

technician was required for optimal operation, thus potentially adding to the cost.

The major cost of simulation training is in faculty and resident time. Thirty-nine simulation sessions, each 3 to 4 hours long, required tremendous time and commitment from the investigators. Participation from other faculty or from retired faculty [10] would help. At UNC, two retired surgeons provided most coaching. Simulation training is most effective, however, when the surgeon teaching in the simulation laboratory is also the operating surgeon in the clinical setting.

Hospitals and insurance companies could potentially benefit by investing in simulation-based training because of improved efficiency and technique of the resident in the operating room and improved patient safety and outcomes.

At the conclusion of the prescribed training, the Consortium produced a curriculum, which is available on the website of the Thoracic Surgery Directors Association (TSDA) [11].

The assessment tools were completed by the participants' instructor. Teaching faculty could be biased toward

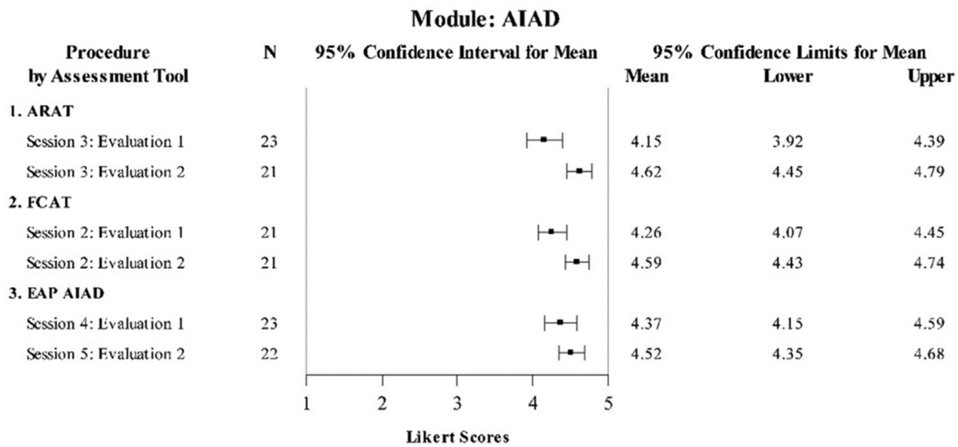

Fig 4. Mean response for each of the scheduled evaluations in the acute intraoperative aortic dissection (AIAD) module. Statistical estimate of the mean is shown for each evaluation. The data show improvement in component task performance with repetitions sustained in the performance of the complete aortic valve replacement procedure. (ARAT = aortic repair assessment tool; EAP AIAD = emergency action plan for acute intraoperative aortic dissection; FCAT = femoral cannulation assessment tool.)

showing improvement in the students they are training. However, it is reasonable to assume that the magnitude of such bias would be small compared with the large magnitudes of improvement we observed. The instructors were experienced and careful at assessing skills. Faculty facility with simulation-based training improved during the study.

A study using similar assessment tools at the TSDA Resident Boot Camp showed that training and experience in use of the OSATS Likert scale tool greatly enhance accuracy [12]. Intraobserver variation was not a factor because the same observer usually assessed a given resident. Substantial improvements in performance seen across all institutions and all residents indicate that the gains seen are real and substantial.

A limitation of the study was the occurrence of missing data. In retrospect, funding a dedicated data manager at each institution would likely have decreased the amount of missing data and the effort required to collect it. The most frequent causes of missing data were impediments to timely effort entering the data, curriculum protocol departures, and data-entry errors in transcribing data from the paper forms. Data collection also decreased during the second year, perhaps a reflection of fatigue over the 2 years of participation. We found no indication that missing data were caused by mechanisms that would induce selection biases. Computerized recording and reporting methodology of assessments used in the Joint Council for Thoracic Surgery Education's "Top Gun" competition would be helpful and should be used in future studies [13].

Table 2. Overall Final Performance Results for Complete Procedures

Module	Mean Scores[a]
Cardiopulmonary bypass (CPB)	4.80 ± 0.12
Coronary artery bypass grafting (CABG)	4.41 ± 0.19
Aortic valve replacement (AVR)	4.51 ± 0.20
Massive air embolism (MAE)	4.68 ± 0.14
Acute intraoperative aortic dissection (AIAD)	4.52 ± 0.17
Sudden deterioration of cardiac function (SDCF)	4.76 ± 0.16

[a] ± two SEs. Scores based on five-point Likert scale (5.0 is perfect score).

AIAD = acute intraoperative aortic dissection; AVR = aortic valve replacement; CABG = coronary artery bypass grafting; CPB = cardiopulmonary bypass; MAE = massive air embolism; SDCF = sudden deterioration in cardiac function.

It is likely that some improvement in surgical skills seen during the study was partly the result of the concurrent clinical experience of the resident. However, we observed improvement within single sessions in which no intervening clinical work occurred. We also saw improvement in response to adverse events for which clinical experience was rarely available.

The optimal timing for a resident to train with the curriculum has not been determined. Simulation-based training has been shown to produce significant surgical skill competency at a very early stage [14]. The combination of basic skills training and the great complexity of whole-task training on the Ramphal simulator offers significant training advantages for all residents. The number of residents who were in traditional 2- or 3-year cardiothoracic surgery training programs (after 5 years of general surgery training) was too small to derive any firm conclusions about how their training success compared with residents in integrated 6-year training programs. Anecdotal experience from institutions where both types of residents were trained indicates that the training was successful in both groups.

In conclusion, overall performance in the component tasks and in the complete procedures improved during simulation-based training, which relied on coaching, deliberate practice, repetition, and progressive simulation complexity. Importantly, simulation imparted skill sets unique to the management of rare adverse events. Use of the curriculum provides a safe environment for learning and has the potential to produce safer surgeons.

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Author Interview: The Author Interview can be viewed in the online version of this article [http://dx.doi.org/10.1016/j.athoracsur.2016.06.062] on www.annalsthoracicsurgery.org.

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EDUCATION

DISCUSSION

DR STEPHEN YANG (Baltimore, MD): I find it extremely ironic that two general thoracic surgeons are discussing a cardiac surgery simulation and patient safety paper, but I am most grateful to The STS for the honor of discussing this manuscript. In my opinion, Dr Feins should be christened the father of modern simulation.

Thank you, Rick, for your innovation and leadership in showing that simulation has added benefit in an era where teaching must go beyond the operating room. We are also indebted to you and your colleagues for running the Boot Camp for 8 years and counting.

This report, unequivocally, is the first of its kind: a government-funded prospective trial on the educational impact of a surgical simulator. Congratulations to you and your esteemed colleagues.

Beyond the massive number of points and the feasibility of this project, this study emphasizes the four areas current surgical training should include: component task surgery, deliberate practice, progressive operative responsibility, and coaching by an experienced surgeon.

Important perhaps in the immediate future is that this simulator might be a useful alternative when stricter rules using animal tissue for simulation will get introduced.

By focusing on the purely technical aspects of these procedures in a nonthreatening environment without the pressure of time and patient outcomes, we as surgical educators are allowed to fully focus on the task at hand of teaching.

My first question centers around the appropriate level of residents used in the study. What effect on the results did you find using second-year residents, since they might have already had significant clinical experience?

In the manuscript, you noted that the first-year residents' curriculum actually ran into the second year and overlapped the concomitant second year residents' timetable.

So based on your results and findings, what year residency do you suggest that the simulator should be employed for both traditional 2/3 year programs, and then for the I6?

DR FEINS: Thank you, Steve. So this study involved just first-year traditional, or fourth- or fifth-year integrated, and then we repeated it with the next group the subsequent year. But it is a very, very important question that you bring up, and I do not know the exact answer.

I do think that this type of training, in my opinion, should be done almost in a mandatory fashion as early as possible and before residents enter the clinical arena. I think it would provide a more efficient process in the operating room, and perhaps one could argue even a safer one.

I would think in the terms of the six-year integrated program, perhaps about the third year. There is not much we can do with the first 5 years of traditional general surgery training, but we started it as close as we could to the beginning of the 3-year cardiothoracic training program, in July.

DR YANG: It also might be useful for residents who get matched into the traditional, if they are at an institution that has the simulator; they could actually start it then.

DR FEINS: I agree.

DR YANG: Secondly, I have a question on the study design. A learner pretest-posttest study is a simple method of testing the effectiveness of the intervention. Why was this not included? This would allow appropriate feedback to the instructors on the optimal learning effects.

DR FEINS: Well, as I understand it, they had a couple of problems with that.

One was to get a baseline with a group of people who had really never done it before. It was difficult to get the pre-evaluation without giving them some instruction to start with.

I think the way the curve sort of goes up is somewhat of a pre-, because the first repetition you could argue was the pre-, and the sixth or seventh is sort of the post- for that particular component task. But that is just the way it was designed.

DR YANG: And then finally, the title of the manuscript includes the phrase "improving patient safety."

How will you measure this in the future?

DR FEINS: Well, that created a significant problem, primarily because the adverse events do not occur frequently enough in the clinical arena for us to be able to compare anything to.

So we are assuming, and I think it is a valid assumption, that exposure to things that you could not get in any other way would improve the safety of it. But as you know, an aortic dissection or a massive air embolism occurs so rarely, we are not going to be able for years and years and years to determine that.

So we have to go the route of flight safety and assume that if you have seen a massive air embolism and you have gone through these protocols, that you will be better prepared when you see them.

DR YANG: So to end, the teaching community appreciates your most charitable donation of the simulation curriculum to the TSDA. And I would like to appropriately dedicate a golf quote to you that perhaps signifies the importance of simulation and actual operating.

"Golf is not like any other sport, where you can take the player out if he is having a bad day. You have to play the whole game."

I thank the Society for the privilege of discussing this paper.

DR FEINS: Thank you. I have experienced that with a number of golf rounds.

DR SETH FORCE (Atlanta, GA): Rick, that is phenomenal work, and hopefully we can expand that to general thoracic surgery with the simulator.

My question is just to get your thoughts on one concept. There has been a lot written about skill acquisition and training, and some of that work has suggested that as you move to high-level skills, you actually widen the separation between participants when you start to work on training.

My question is your thoughts on how this may be used in the future, in stratifying residents, and whether in the future, this will even be used to suggest which residents may not even be able to become adequate cardiothoracic surgeons. Thank you.

DR FEINS: That is a very important point. You know, we have a lot of tools now with this study and with others at our disposal for us to use. And you know if you believe in the 10,000 hours and talent is overrated concepts, what you would say is if you have a proper training paradigm and a properly motivated student, that you can train many, many people, most all people to the level of mastery.

So I think that what this does show is that if you can be in an environment that is educationally sound and repeat it over and over and over again, that a lot of these folks who appear to be deficient will be brought up to an appropriate level.

We have looked at trying to use this for selecting residents. With the Boot Camp experience and with this study we have some idea of simulation's potential, but I do not think we are in a situation yet where we are able to use this as selection criteria.