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.**

(Ann Thorac Surg 2017;103:312–21)

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,

Accepted for publication June 20, 2016.

Presented at the Fifty-second Annual Meeting of The Society of Thoracic Surgeons, Phoenix, AZ, Jan 23–27, 2016.

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Drs Feins, Coore, and Ramphal disclose a financial relationship with KindHeart, Inc; Dr Mokadam with HeartWare, Inc, and St. Jude Medical.

0003-4975/$36.00
http://dx.doi.org/10.1016/j.athoracsur.2016.06.062

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 deidentified 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.