Development of a 3-D printing-based cardiac surgical simulation curriculum to teach septal myectomy

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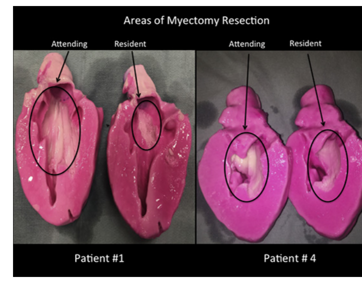
ABSTRACT

Objective: We sought to develop a 3-D printing-based simulator for teaching extended septal myectomy to trainees in cardiothoracic surgery (clinical postgraduate year 4-7). This procedure is difficult to teach because of generally unfamiliar and highly variable anatomy, limited visibility for the assistant, and significant potential complications.

Methods: A curriculum using multimedia didactics and 3-D print-based patient-specific surgical simulation was implemented. Six identical 3-D prints were constructed for each of 5 consecutive patients. Preoperative septal myectomy was performed on each printed heart by an attending surgeon and 5 residents. Model myectomy specimen volumes were measured according to liquid displacement. All print resections were videotaped and blindly evaluated by 3 attending surgeons. Pre- and post-test evaluations, and a survey tool were also used to evaluate the curriculum.

Results: Baseline myectomy resection volumes differed significantly (attending 15 cm^3 vs resident 3.1 cm^3; $P < .05$). Residents resected increasingly larger volumes of tissue over the course of the study. Initial resection volume (compared with faculty) increased by 0.82 cm^3 per resection (95% confidence interval, 0.37-1.3 cm^3; $P < .0001$). Total resection volume (compared with faculty) increased by 3.6 cm^3 per resection (95% confidence interval, 2.4-4.9 cm^3; $P < .0001$). The residents' survey assessment of the simulator was favorable.

Conclusions: A patient-specific 3-D printing-based simulation module shows promise as a tool to augment and improve cardiothoracic resident training in septal myectomy. The residents were quickly able to perform resections on par with the attending. Residents rated the simulator favorably. Each resident benefited by experiencing the variable anatomy of 5 separate patient-specific models. (J Thorac Cardiovasc Surg 2018;■:1-10)



Myectomy done by attending and resident at the beginning (*left*) and near the end of the study (*right*). *Black circles* show the area of resection.

Central Message

A 3-D print-based simulation curriculum was used to augment cardiothoracic resident training in septal myectomy.

Perspective

Septal myectomy is a difficult procedure to teach in most training programs because of low surgical volume, generally unfamiliar and highly variable anatomy, limited visibility for the assistant, and significant specific complications. A simulation curriculum using patient-specific 3-D prints is useful to augment resident education and training for this specific procedure.

EDU

Surgical myectomy for treatment of left ventricular outflow tract (LVOT) obstruction in patients with hypertrophic cardiomyopathy is a conceptually simple, yet challenging 3-D procedure. Septal myectomy is difficult to teach compared with many cardiac procedures because of highly variable anatomy that is generally unfamiliar to residents, limited visibility for the assistant, significant specific complications, and low surgical volume in all but a few institutions.[1]

We previously reported on the use of patient-specific 3-D printed models for deliberate practice and surgical rehearsal (by an attending surgeon) of extended septal myectomy for hypertrophic cardiomyopathy.[2] The models are printed in a proprietary hydrogel medium and are able to be manipulated in ways meaningful to a surgeon. This medium is overall stiffer and less deformable than myocardium but is able to be incised, cut, and sutured. It was apparent from the initial experience that this model might also have educational utility.[2] The objective of this study was to development and use a 3-D print-based simulation curriculum to

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Abbreviations and Acronyms

CABG = coronary artery bypass grafting
CI = confidence interval
LVOT = left ventricular outflow tract
VSD = ventricular septal defect

augment traditional instruction of senior cardiothoracic residents regarding extended septal myectomy. We recognized our own residents were undertrained in this procedure and hypothesized that a simulation-based curriculum using patient-specific 3-D printed models might have utility.

Within surgical disciplines, teaching and learning of specific procedures are paramount and educational paradigms and pedagogy continue to evolve. Simulation has become increasingly used as an adjunct to operating room experience and the concept of deliberate practice is gaining traction among surgeon-educators.[3,4]

METHODS

Curriculum

Cognitive assessment. Each resident completed a 10 item pretest (Appendix E1) before the didactic lectures. The test was readministered at the completion of the curriculum (after all simulations and cases) and scores were compared.

Didactics. A curriculum composed of 2 didactic lectures (1 by a cardiac surgeon experienced in myectomy and 1 by a radiologist with 3-D printing expertise), selected readings,[5-7] and a surgical video[8] was designed and implemented. The readings and video were provided electronically and the lectures given before beginning the simulation portion of the curriculum.

Simulations. For each of 5 patients who were to undergo myectomy, 6 identical 3-D printed models were constructed. The methodology for printing and performing myectomy on the printed models has been previously published.[2] Extended septal myectomy of the printed model was performed by an attending surgeon and each of the 5 study residents (Figure 1, Video 1). The attending and each resident performed resection on separate models for all 5 patients (30 models). All model resections were videotaped. Each resection began with identification of the relevant anatomy including the right coronary ostium, right coronary cusp aortic annulus, membranous ventricular septum, and right and left fibrous trigones. The volume of print resected was measured according to liquid displacement in all cases. Measurements were taken of the initial piece resected as well as the total volume of resection specimen. We assessed differences between faculty and resident resections over the course of the experiment using mixed effects linear regression with random intercepts for each resident.

No technical instruction, other than provided in the didactic materials, was given before resection of patient 1 models. This allowed for the resident resection of that model to serve as a baseline. All residents reviewed the patient 1 attending model alongside a representative patient 1 resident model before working with the patient 2 model. Some basic technical feedback was given during patients 3 to 5 model simulation sessions. This feedback was provided by J.L.H., who was the attending surgeon on all cases and was also one of the video graders.

The entire study was conducted during an approximate 6-month period. The time between the didactics and first patient was approximately 3 weeks.

FIGURE 1. Photograph showing the setup of the simulator within an empty operating room. The 3-D print is positioned within a basin placed in the chest cavity of a mannequin. A sternal retractor and drapes help to recreate the field. Basic instruments and the graduated cylinder used to measure resection volumes are shown on the Mayo stand.

The remainder of the patients were spread relatively evenly over the ensuing 5 months.

Faculty scored all model resection videos using a Likert scale-based tool with clinical performance anchors (Appendix E2). Scores were analyzed using mixed effects in a similar fashion. All faculty assessment scores were averaged to provide a mean faculty assessment score for each resident, for each model. Assessment of faculty agreement was performed using the mean faculty assessment score adjusting for fixed effects at the resident and model levels. A logistic regression model was used to model faculty status according to faculty assessment mean scores.

Survey assessment. An anonymous survey tool was developed, on the basis of a tool used for a similar simulation study,[9] and administered after completion of the curriculum. The tool asked residents to assess several domains of the simulator including physical attributes and realism, ability to perform key tasks, readiness for educational use, value as a teaching tool, and worthiness related to effort and future practice.

Institutional review board approval was waived for this study. All residents assented to full participation in the curriculum.

RESULTS

Cognitive Assessment

The pre-curriculum mean test score was 5.4 (SD, 2.61), which increased to 7 (SD, 0.89) for the post-test ($P = .04$). This indicates overall knowledge improvement and retention of knowledge gained during the course of a curriculum spanning several months.