Use of 3-Dimensional Printing Technology and Silicone Modeling in Surgical Simulation: Development and Face Validation in Pediatric Laparoscopic Pyeloplasty

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OBJECTIVES: Pediatric laparoscopy poses unique training challenges owing to smaller workspaces, finer sutures used, and potentially more delicate tissues that require increased surgical dexterity when compared with adult analogs. We describe the development and face validation of a pediatric pyeloplasty simulator using a low-cost laparoscopic dry-laboratory model developed with 3-dimensional (3D) printing and silicone modeling.

DESIGN AND SETTING: The organs (the kidney, renal pelvis, and ureter) were created in a 3-step process where molds were created with 3D modeling software, printed with a Spectrum Z510 3D printer, and cast with Dragon Skin 30 silicone rubber. The model was secured in a laparoscopy box trainer. A pilot study was conducted at a Canadian Urological Association meeting. A total of 24 pediatric urology fellows and 3 experienced faculty members then assessed our skills module during a minimally invasive surgery training course. Participants had 60 minutes to perform a right-side pyeloplasty using laparoscopic tools and 5-0 VICRYL suture. Face validity was demonstrated on a 5-point Likert scale.

PARTICIPANTS AND RESULTS: The dry-laboratory model consists of a kidney, a replaceable dilated renal pelvis and ureter with an obstructed ureteropelvic junction, and an overlying peritoneum with an inscribed fundamentals of laparoscopic surgery pattern-cutting exercise. During initial validation at the Canadian Urological Association, participants rated (out of 5) 4.75 $\pm$ 0.29 for overall impression, 4.50 $\pm$ 0.41 for realism, and 4.38 $\pm$ 0.48 for handling. During the minimally invasive surgery course, 22 of 24 fellows and all the faculty members completed the scoring. Usability was rated 4 or 5 by 14 participants (overall, 3.6 $\pm$ 1.22 by novices and 3.7 $\pm$ 0.58 by experts), indicating that they would use the model in their own training and teaching. Esthetically, the model was rated 3.5 $\pm$ 0.74 (novices) and 3.3 $\pm$ 0.58 (experts).

CONCLUSIONS: We developed a pediatric pyeloplasty simulator by applying a low-cost reusable model for laparoscopic training and skills acquisition. The model's usability, realism, and feel are good, it can be imaged under common modalities, and it shows promise as an educational tool. (J Surg 71:762-767. © 2014 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: simulation, pyeloplasty, surgical training, laparoscopy

COMPETENCIES: Practice-Based Learning and Improvement, Systems-Based Practice, Interpersonal and Communication Skills

INTRODUCTION

The rapid adoption of laparoscopic surgery in pediatrics has afforded families with a minimally invasive option for many reconstructive and extirpative surgeries. However, skills training in laparoscopic pediatric urology may have difficulty keeping pace, as there are few simulation tools for technical skills acquisition. Furthermore, in pediatric surgery, surgical spaces and tissues are smaller, suture material is finer, and target organs may be more delicate

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  1931-7204/$30.00
http://dx.doi.org/10.1016/j.jsurg.2014.03.001

than in adult surgery. In addition, manufacturers of surgical-simulation modules may focus more on adult analogs because simulators for adult surgery may have a broader customer base. Pediatric pyeloplasty may be the procedure of choice for enabling pediatric urology trainees to learn laparoscopic skills, yet cases are not frequent enough to provide sufficient access to maintain the necessary skills and fully master the procedure. The cost of traditional surgical training is substantial,[1] suggesting the need for improved methods of skills acquisition. Traditionally, animal and cadaveric models have been used in teaching. However, these models are costly, meant for single use, and require the use of specialized facilities. Furthermore, animals may not fully reflect human anatomy, and cadaveric models lack perfusion and other qualities related to living tissue.

To address the need for better training, simulation tools using tissue phantoms and virtual reality–based dry-laboratory platforms have been developed as effective tools[2,3] that allow novice surgeons to acquire and practice surgical skills before working on a patient. This learner-centered training paradigm allows for mistakes in a zero-risk environment, repetitive practice, graduated advancement, and multiple clinical scenarios. Task simulators also exist for isolated dissection, suturing, and knot tying, as well as for laparoscopic skills. There is great value in providing a more complete experience so that trainees can learn and practice all the surgical and technical steps for the entire procedure. Virtual simulators are becoming more prevalent as a reusable platform with no tissue exposure. However, these systems are very expensive and are limited in their ability to mimic tool-tissue interactions as few have properly simulated haptic feedback.[4,5] Providing trainees with the proper feel as they cut and manipulate tissue is highly important, and not having proper force feedback can have negative consequences on training.[6] If the tissue does not have the appropriate mechanical properties, trainees may apply improper forces when they transition to patients and take unnecessary risk, causing traumatic injury.

An example of a successful simulation tool is the fundamentals of laparoscopic surgery (FLS) program,[7] a combined effort by the Society of American Gastrointestinal and Endoscopic Surgeons and the American College of Surgeons. This program teaches and evaluates technical skills for laparoscopic surgery through tasks that test instrument navigation, instrument coordination, cutting, and knot tying. A series of exercises that test these skills are presented in a laparoscopic box trainer, and laparoscopic tools are used. Recently, this system has been adapted to suit the needs for training in pediatric minimally invasive surgery (MIS).[8,9] This program inspired our research team to develop a low-cost laparoscopic pyeloplasty simulator using 3-dimensional (3D) printing technology and silicone modeling for training urology fellows.

The 3D printing technology has opened up opportunities for designing and prototyping structures for surgical training. As the technology becomes more affordable and prevalent, research laboratories are increasingly using it as an efficient way to create tools to supplement the training curricula. We describe our development and initial validation of a low-cost pediatric laparoscopic pyeloplasty simulator using a 3D-printed pyeloplasty dry-laboratory model that was evaluated by novices and expert urologists. We aimed to create a device to enable increased access to training so that novices can prepare in advance for operating on their first patient. This article describes the simulator development, initial face validation, and lessons learned for future technical work and clinical training.

METHODS

As the study rests on an anonymous survey and is imbedded in an educational forum with the sole purpose of assessing a surgical model, it did not meet the definition of human research that requires research ethics review or approval, and hence the REB review was waived.

Model Development

The pediatric pyeloplasty model was created using a 3-step process: 3D models of the target organs and their respective negative-volume molds were created with 3D modeling software, the molds were manufactured using a 3D printer, and the molds were cast with silicone rubber. For the simulator, the target organs were the kidney (dimensions of 60×40 mm^2), dilated renal pelvis (22-mm short axis and 29-mm long axis) leading to an obstructed ureteropelvic junction (UPJ), ureter (inner diameter 5 mm, wall thickness <1 mm), and overlying peritoneum whereby simulating a traditional transmesenteric approach. The organ shapes were created from combining geometrical shapes, such as spheres and toroids to approximate the organ. The model was scaled to the size of an approximately 10-month old[10,11] to reflect the smaller anatomy of an infant. The organ molds were created by subtracting the organ volume from a larger rectangular volume through creation of negative space. After the molds were created, they were printed using a Spectrum Z510 3D printer (3D Systems, Rock Hill, SC). The 3D printer consists of 2 chambers, feed and build, where the system deposits a thin 0.04-in. layer of powder (ZP-131) and sprays a bonding agent (ZB-60) to form a single layer of the mold. This is repeated to build up the entire model. On a microscopic level, the model is a porous matrix. After printing, the mold was removed from the build chamber and air blasted with compressed air to remove excess powder. It was dipped in an infiltrant solution (Z-Bond 90) where the solution penetrated to a depth of 1-2 mm into the porous matrix and it hardened to a smooth surface. The molds were then cast with colored Dragon Skin 30 silicone rubber (Smooth-On Inc, Easton, PA) that was mixed in predetermined ratios[12] with Slacker Tactile Mutator (Smooth-On Inc, Easton, PA) to mimic tissue properties. The Dragon Skin 30 silicone rubber consists of a 2-part mixture consisting