Comprehensive Training Curricula for Minimally Invasive Surgery

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Abstract

Background The unique skill set required for minimally invasive surgery has in part contributed to a certain portion of surgical residency training transitioning from the operating room to the surgical skills laboratory. Simulation lends itself well as a method to shorten the learning curve for minimally invasive surgery by allowing trainees to practice the unique motor skills required for this type of surgery in a safe, structured environment. Although a significant amount of important work has been done to validate simulators as viable systems for teaching technical skills outside the operating room, the next step is to integrate simulation training into a comprehensive curriculum.

Objectives This narrative review aims to synthesize the evidence and educational theories underlining curricula

development for technical skills both in a broad context and specifically as it pertains to minimally invasive surgery.

Findings The review highlights the critical aspects of simulation training, such as the effective provision of feedback, deliberate practice, training to proficiency, the opportunity to practice at varying levels of difficulty, and the inclusion of both cognitive teaching and hands-on training. In addition, frameworks for integrating simulation training into a comprehensive curriculum are described. Finally, existing curricula on both laparoscopic box trainers and virtual reality simulators are critically evaluated.

Introduction

Surgical residency programs have traditionally relied on the operating room to teach surgical skills to residents through graded responsibility under direct supervision. However, this strategy is no longer entirely feasible. New limits on resident duty hours have resulted in less time and fewer opportunities for instruction in the operating room.¹ In addition, patient safety concerns have made it undesirable for novice surgeons to learn procedures on real patients. As such, it has become advantageous to shift a significant amount of resident technical skills training from the operating room to the surgical skills laboratory. The advent of new technology, such as laparoscopic (minimally invasive) surgery, has similarly contributed to the need for systematic skills training in a safe, simulated environment. The technical skill set for laparoscopic surgery is different from that of open surgery owing to altered depth perception, diminished tactile feedback, and the requirement of developing video-eye-hand coordination, all

factors that contribute to the long learning curve for this type of surgery.²

Simulation lends itself well as a method to shorten the learning curve for minimally invasive surgery (MIS) by allowing trainees to practice these new motor skills in a safe environment outside the operating room. Many different types of simulators exist to teach laparoscopic technical skills, including laparoscopic box trainers and virtual reality (VR) simulators. The effectiveness of these systems has been well documented in both randomized controlled trials as well as in several systematic reviews.^{3–12} A significant amount of important work has been done to validate simulators as viable systems for teaching technical skills outside the operating room. The next step is to integrate simulation training into a comprehensive curriculum. The idea of using structured curricula for technical skills training outside the operating room is not new; however, most currently used curricula have been developed in an ad hoc manner, are used only locally at individual institutions, and are not well validated.

This narrative review aims to synthesize the evidence and educational theories underlining curricula development for technical skills both in a broad context and specifically as it pertains to minimally invasive surgery. The first part of the review will outline the critical aspects of simulation training. The second part will outline frameworks for integrating simulation training into a comprehensive curriculum for technical skills training. Finally, the third section will describe existing curricula developed for MIS procedures.

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Critical Components of Simulator Training

Evidence exists supporting the use of simulators for surgical training. However, not all training on simulators is equal. As Aggarwal and colleagues¹³ state, it is not solely the simulator, but also the type of training on the simulator that determines the degree of transference of the identified skill to the operative setting. Key features of simulation training include the optimal provision of feedback, deliberate practice, training to proficiency, the opportunity to practice at varying levels of difficulty, and the inclusion of both cognitive teaching and hands-on training.

Feedback

Feedback can be divided into intrinsic and extrinsic feedback. Intrinsic feedback is generated within the performer of the task and consists of the visual, auditory, or haptic perceptions during task performance.¹⁴ Extrinsic feedback is provided by an external source, usually an expert observer, and aims to enhance intrinsic feedback.¹⁴ Extrinsic feedback is the type of feedback that one usually thinks of in surgical education, where an expert, or staff physician, provides a meaningful critique designed to improve the technical performance of a trainee. Studies have shown that extrinsic feedback accelerates technical skill acquisition.^{15–18} The type of extrinsic feedback also seems to affect technical performance. Summary expert feedback, or feedback that occurs at task completion, is more efficacious than concurrent feedback, which occurs as the learner is performing the task.¹⁹ Both forms of feedback result in equal technical learning initially. However, trainees who received summary feedback outperformed residents who received concurrent feedback at a 1-month retention test, which may be related to either the fact that concurrent feedback distracts from the intrinsic feedback naturally present or that learners may use concurrent feedback as a crutch.¹⁹ It also has been shown that expert feedback is more useful for trainees than information relating to motion efficiency.¹⁷ It is therefore important when developing a surgical skills curriculum to incorporate the provision of feedback into technical skills training. For feedback to be of maximal use to the trainee, it should be provided by an expert, at the conclusion of a motor task, and in a limited fashion.

Practice Schedule

It is intuitive that practice results in an improvement in technical performance. However, surgical trainees are limited in the amount of time that they have available for practice outside the operating room. What type of practice is most conducive to learning a technical skill efficiently? Ericsson²⁰ advocates deliberate practice as being essential in the development of technical expertise. Deliberate practice refers to the idea that practice should be mindful and related to the representative context of the target performance, with feedback that focuses on increasingly refined aspects of

performance.²⁰ The distribution of practice sessions can also affect the efficiency and quality of learning. Moulton et al²¹ demonstrated, in a randomized controlled trial, that distributed, as opposed to massed, practice results in improved acquisition and transfer of a technical skill learned on a simulated model. These findings have also been replicated in other work.^{22,23} It is thought that distributed practice allows the learned skills to consolidate between practice sessions.²⁴ Currently, it is thought that practice sessions ranging from 45 minutes to 1 hour are optimal for learning, although this is based primarily on expert opinion, rather than on well-designed studies.^{14,25}

Proficiency-Based Training

The goal of simulation training is to develop what Gallagher and colleagues²⁴ term the *pretrained novice*. A pretrained novice is a trainee who has trained by using simulation to a point where many of the psychomotor skills and spatial judgments are automated. As a result, in the operating room, the trainee can focus on higher-level skills such as learning the steps of the operation or how to manage complications. Gallagher et al²⁴ state that the goal of any surgical training program should be to ensure that junior surgical residents practice in a simulated environment until basic psychomotor tasks are automated. How long does it take for automaticity to occur? Gallagher and colleagues argue that it is different for every individual trainee. As a result, they advocate training on a simulator until residents reach a level of benchmark performance that is established from having experts performing the task that trainees will be using to train. The efficacy of proficiency-based rather than time-based training is well supported by the literature.^{26–29} The fundamentals of curriculum design, however, are complicated by our unclear understanding of surgical expertise.¹⁴ The definition of “expert” could conceivably alter depending on the task. Moreover, it has not been well established in the literature how many experts are required to develop these expert levels of proficiency or how often trainees should perform the task at the expert level in order to have attained proficiency.

Variability of Practice

In a surgical skills curriculum, practice of motor tasks should ideally occur at varying levels of difficulty. Ali et al³⁰ demonstrated that practice at a higher level of difficulty on a VR simulator resulted in increased learning, compared to practice simply at an easier level. Moreover, Aggarwal et al³¹ demonstrated that participation in a VR training program that allowed progression between various levels of difficulty results in increased learning. It has also been shown that difficult training conditions can result in an improved performance on the simulator, although these do not necessarily translate to the operating room.³² Different levels of training and progression through a sequentially more difficult curriculum could stimulate trainees’ interest

and increase their motivation, 2 factors that are deemed essential for learning and for the long-term effectiveness of surgical skills curricula within residency training programs.¹⁴

Cognitive Teaching

Although initially the field of surgical simulation emphasized solely ex vivo technical skills training to learn a specific technical skill or operative procedure, increasingly opinion leaders in surgical education are emphasizing cognitive learning as an essential element in simulation training.¹⁴ The importance of cognitive training is emphasized in several studies. Tang et al³³ demonstrated that most errors performed by trainees during simulated training occurred not owing to technical mistakes, but rather from a knowledge gap, including a lack of understanding of the correct sequence of steps in a particular task. Similarly, the advantages of cognitive training were demonstrated in a single-blinded randomized study in which residents allocated to a didactic training group (which included relevant anatomy, steps of a procedure, potential errors and complications) outperformed a similar group of non-cognitively trained residents on a virtual reality simulator.³⁴ This study emphasizes that cognitive training not only improves an understanding of a particular operation or task but also improves its execution. It has also been shown that the addition of cognitive training to a technical skills curriculum, even if it reduces the amount of time available to practice a technical skill, does not affect the amount of technical skill learning that occurs.³⁵

Framework for Integrating Simulation Into a Comprehensive Curriculum

After defining the essential components of technical skills training on simulators, the next step in curricular development is to incorporate simulation training into a comprehensive evidence-based curriculum. Several frameworks for curricula development have been described in the literature.

Sarker and Patel³⁶ hypothesize that a trainee should progress through a curriculum in the following manner: watching a simulated task, performing a simulated task, feedback, watching a real task, and finally, performing a real task. Ultimately, all of the components of the curriculum are interconnected and relate back to one another.³⁶ Stefanidis and Heniford¹⁴ build on this idea by describing a curriculum that commences with a baseline assessment, followed by deliberate practice with feedback in a simulated environment, training to proficiency, and a posttraining assessment. The concept of Aggarwal et al³⁷ is similar (FIGURE). The framework this group describes contains knowledge-based learning, training in a laboratory environment, ensuring that the learned skills transfer to a real environment, and ultimately granting privileges for

independent practice. While the overall principles espoused by the authors are similar, the framework described by Aggarwal et al³⁷ is perhaps the most current, as it specifically includes knowledge-based learning as well as hands-on training as a critical component in curricular design.

Curricula for MIS Procedures

Although various frameworks for curricular design have been proposed, and extensive work has been done to validate both laparoscopic box trainers and VR simulators as viable models to teach technical skills, few comprehensive curricula for training in MIS have been described.

Curricula for Box Trainers

The Fundamentals of Laparoscopic Surgery (FLS) is likely the most well-described curriculum in the literature for basic laparoscopic skills. The FLS program consists of both a cognitive and a technical skills component.³⁸ The cognitive component is didactic and covers material related to preoperative, intraoperative, and postoperative considerations for laparoscopic procedures.³⁸ The technical component is based on the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills Program.³⁸ In the technical training component, trainees perform a series of basic tasks in a laparoscopic box trainer. These tasks include pattern cutting, peg transfer, endoloop, intracorporeal stitch and square knot, and extracorporeal stitch and square knot. At the end of the curriculum, trainees are assessed by a multiple-choice test and a technical skills assessment. The FLS program has demonstrated feasibility, construct validity (the ability to distinguish between expert and novice performance), and predictive validity (the degree of correlation between performance on the simulator and performance in a real clinical situation).^{39,40} Proficiency-based curricula for FLS have also been described, in which maximum time and error scores for each of the 5 FLS tasks have been determined by the performance of 2 MIS fellowship-trained surgeons.⁴¹

Practice using the proficiency-based curriculum has been shown to improve the technical skills of junior residents to those of senior residents after only 7.5 hours of simulator training.⁴² In addition, a randomized controlled single-blinded trial demonstrated that practice with the proficiency-based curriculum resulted in an improved technical performance in the operating room.⁴³ Importantly, technical skills learnt on the FLS system are resistant to decay and have been shown to persist on a porcine model for up to 5 months.⁴⁴ In 2005, the Society of American Gastrointestinal and Endoscopic Surgeons and the American College of Surgeons joined together to manage the FLS program.³⁸ Currently, FLS certification is required for American surgical residents to write their surgical board examinations.

The FLS curriculum closely follows the framework described by Aggarwal et al.³⁷ The Fundamentals of Laparoscopic Surgery consist of a cognitive component and a technical skills component that are both assessed, with these assessments ultimately involved in granting privileges for independent practice. In addition, as described above, the FLS simulation training component of the curriculum has been extensively validated and been shown to transfer to the real environment. The FLS curriculum as a whole represents a good example of an evidence-based comprehensive curriculum designed to teach basic MIS technical skills. With the exception of intracorporeal suturing, the FLS program teaches quite basic laparoscopic skills. Given the strong evidence behind FLS training, general surgical programs should consider requiring

residents to pass the FLS course before participating in the operating room. This fits with Gallagher's idea of the "pretrained novice" in which a certain portion of the learning curve would be surmounted before learning in a real clinical environment. It would not only increase learning efficiency in the operating room but also patient safety.

Curricula on Virtual Reality Simulators

Similar in concept to the FLS curriculum, a VR curriculum for basic laparoscopy training was developed by Panait et al⁴⁵ in 2008. This curriculum consists of a proficiency-based training component and an examination component. Benchmark levels for 17 virtual reality tasks were established by the performance of 1 MIS surgeon. The curriculum consists of trainees practicing the 17 modules until they reach expert levels of proficiency.⁴⁵ At that point they take an examination (which consists of 7 modules). Construct validity has been demonstrated for this curriculum.⁴⁵ Currently, residents at Yale University (New Haven, Connecticut) must pass the curriculum before performing laparoscopy in the operating room. The success of this curriculum prompted the authors to develop a similar VR curriculum, the Yale Advanced Laparoscopic Skills Curriculum, which consists of the same tasks as the basic curriculum, but at a greater level of difficulty.⁴⁶ In a nonrandomized prospective study of 23 surgical residents, the authors demonstrated that training on this advanced curriculum contributed to an increase in FLS score for senior residents.⁴⁶

Similar proficiency-based curricula for basic laparoscopy training that describe progression through tasks at increasing levels of difficulty on a virtual reality simulator have also been described by Aggarwal et al^{28,31} and Sinha et al.⁴⁷ Although these described curricula show some preliminary evidence of construct validity and conform to current educational standards of proficiency-based training, at this point, studies have not been performed investigating whether practice using these curricula results in improved performance in the operating room.

Currently, in the literature, only 1 study describes a curriculum for a laparoscopic surgical procedure. Aggarwal et al¹³ describe a proficiency-based virtual reality curriculum for laparoscopic cholecystectomy. Construct validity, expert levels of proficiency, and learning-curve data were assessed for 9 basic tasks, 4 procedural tasks, and 1 full procedural task on the LapMentor VR simulator (Simbionix Corporation, Cleveland, Ohio). Ultimately, only 8 basic tasks, 3 procedural tasks, and the full procedural task showed acceptable construct validity.¹³ The design of this curriculum is evidence based in that construct validity was established for curricular tasks and expert levels of proficiency were determined by the median expert scores. In addition, the authors emphasize that training should take place in distributed practice sessions separated by 1 hour

each with a maximum of 2 practice sessions per day. At this point, more work needs to be done to ensure that skills learned on this curriculum transfer to the operating room.

Unlike the FLS program, the current curricula for VR training in MIS procedures are in their relative infancy. More work needs to be done to ensure that the learned skills transfer to the operating room and also to include a cognitive aspect of training in the curriculum. Also, while Panait's group⁴⁵ requires that residents pass the curriculum before participating in operating room activities, which adheres to the final component of Aggarwal's curricular framework,³⁷ it may be argued that this is somewhat premature. Before determining how to grant privileges for independent practice, it is essential to validate the curriculum as a whole and ensure the transferability of skills to a real clinical environment. These early VR curricula are important to expand upon and develop since, unlike the box trainers used in the FLS program, VR simulators can be more versatile. Virtual reality simulators can be programmed to contain tasks at different levels of difficulty and ultimately, 1 simulator can potentially contain several curricula, which could accommodate trainees at multiple levels in multiple residency programs. Although FLS is the current "gold standard" for basic MIS skills training, there is a need to develop MIS curricula for both more advanced procedural skills as well as for operations in their entirety.

Conclusions

Although there has been much written in the literature relating to effective frameworks for technical skills curricula, as well as validation of individual simulation tools, other than the FLS curriculum, few evidence-based comprehensive curricula have been developed for MIS surgery. As several other authors have articulated, it is time to move beyond individual validation studies for simulators and to think about developing surgical skills curricula in an evidence-based manner. These curricula should include both a technical and a cognitive skills training component.

Technical skills training should be proficiency based, longitudinal, with the opportunity for deliberate, distributed practice, as well as practice at varying levels of difficulty. In addition, as learners progress through the curriculum, they should be provided with summary expert feedback. Ultimately, the effectiveness of the curriculum should be assessed by well-designed trials looking at outcomes of real surgical procedures in the operating room. The paucity of described and validated curricula for MIS procedures in the literature speaks to the fact that curricular design and validation as articulated above is intensive in terms of expert time commitment, cost, and resources.

A way of circumventing some of these difficulties is to foster collaborative projects between institutions in order to increase the pool of resources available for the intensive process of design and validating evidence-based curricula. This is important not only to increase the feasibility of this

endeavor, but also because it will help to ensure that the developed curricula are reflective of national or international practice rather than simply practice at 1 institution. Although this article examined curricula specifically designed for minimally invasive surgical procedures, the theories behind technical skills curricular development can be applied to any branch of medicine that involves the acquisition of a specific technical skill. The development and implementation of evidence-based technical skills curricula for surgical procedures has the potential to make a large impact, not only on the educational experience of our medical trainees, but also on patient safety inside the operating room.

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