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Creating a Proficiency-based Remote Laparoscopic Skills Curriculum for the COVID-19 Era

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OBJECTIVE: Social distancing restrictions due to COVID-19 challenged our ability to educate incoming surgery interns who depend on early simulation training for basic skill acquisition. This study aimed to create a proficiency-based laparoscopic skills curriculum using remote learning.

DESIGN: Content experts designed 5 surgical tasks to address hand-eye coordination, depth perception, and precision cutting. A scoring formula was used to measure performance: cutoff time - completion time - (K × errors) = score; the constant K was determined for each task. As a benchmark for proficiency, a fellowship-trained laparoscopic surgeon performed 3 consecutive repetitions of each task; proficiency was defined as the surgeon’s mean score minus 2 standard deviations. To train remotely, PGY1 surgery residents (n = 29) were each issued a donated portable laparoscopic training box, task explanations, and score sheets. Remote training included submitting a pre-test video, self-training to proficiency, and submitting a post-test video. Construct validity (expert vs. trainee pre-tests) and skill acquisition (trainee pre-tests vs. post-tests) were compared using a Wilcoxon test (median [IQR] reported).

SETTING: The University of Texas Southwestern Medical Center in Dallas, Texas

PARTICIPANTS: Surgery interns

RESULTS: Expert and trainee pre-test performance was significantly different for all tasks, supporting construct validity. One trainee was proficient at pre-test. After 1 month of self-training, 7 additional residents achieved proficiency on all 5 tasks after 2-18 repetitions; trainee post-test scores were significantly improved versus pre-test on all tasks (p = 0.01).

CONCLUSIONS: This proficiency-based curriculum demonstrated construct validity, was feasible as a remote teaching option, and resulted in significant skill acquisition. The remote format, including video-based performance assessment, facilitates effective at-home learning and may allow additional innovations such as video-based coaching for more advanced curricula. (J Surg Ed 79:229–236. © 2021 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: Laparoscopic curriculum, at-home simulation training, remote training, COVID-19. Abbreviations: TC, time to task completion

COMPETENCIES: Practice-Based Learning and Improvement

INTRODUCTION

New surgical interns seek early skills training using simulation in order to gain requisite abilities for operative practice. Access to this training was challenged as the COVID-19 pandemic resulted in social distancing orders affecting multiple aspects of surgical training, including access to our simulation center. In response, we identified a need for at-home laparoscopic skills training to offer access to and practice for basic laparoscopic skills acquisition. Multiple publications report various attempts to creatively maintain skills training via remote methods. These curricula have focused on using at-home or easily accessible products, a variety of low- to high-fidelity products, and spanned many different disciplines of surgery.1-5

Support for at-home laparoscopic training has been growing in recent literature. Support first came with evidence of skill acquisition and construct validity for various developed tasks.6-11 Randomized trials also demonstrated that skill acquisition with at-home trainers...
was equivalent to that of onsite trainers, proving this as a reasonable training alternative.\(^{12}\) Despite some perceptions that competing interests may limit trainee engagement with at-home trainers, data support that residents desire using at-home trainers and are more likely to perform deliberate practice with them in shorter and more frequent sessions.\(^ {10,13-15}\) Furthermore, access to at-home training allows more control in practice scheduling, thereby eliminating practice when trainees are fatigued or frustrated.\(^ {15}\)

Proficiency-based simulation training has been garnering support since the early 2000s when data proved that learner skill acquisition varied vastly in terms of previous metrics such as time spent or repetitions; performance was better described by using proficiency-based metrics and established goals for training.\(^ {16}\) Proficiency-based training has also demonstrated transference of skills to the operating room and decreased surgical skills decay.\(^ {17-19}\)

Despite the availability of at-home laparoscopic curricula, few programs have used a proficiency-based training model. Furthermore, none to our knowledge have focused on skill acquisition particularly in laparoscopy-naïve learners. The COVID-19 pandemic identified the need for remote proficiency-based training that supports skill acquisition for novice learners. Our institution has had previous experience and success with developing similar curricula to train naïve interns in basic skills such as hand-eye coordination and depth perception later applicable to the more complex tasks of the Fundamentals of Laparoscopic Surgery (FLS) program (www.flsprogram.org). We have not however previously implemented remote laparoscopic training.\(^ {20}\) Using a methodology similar to our previous curriculum, we aimed to develop a cost-effective and feasible proficiency-based remote laparoscopic skills curriculum to train basic skills for matriculating general surgery interns.

**MATERIAL AND METHODS**

**Curriculum Development**

This study was reviewed and approved by the University of Texas Southwestern Institutional Review Board and performed in collaboration with the UT Southwestern Simulation Center. We assembled at-home laparoscopic box trainers using previously donated laparoscopic instruments (graspers, scissors, and needle drivers) and a new donated Ethicon kit consisting of a compressible box trainer, a USB digital camera, and various supplies for task development (e.g., saucers, beads, pegs, rubber bands, and clips). Two content experts first determined the essential laparoscopic skills represented in our traditional in-person basic laparoscopic skills curriculum\(^ {17,19}\) and then developed 5 representative tasks that could be performed with the available equipment (Fig. 1, Table 1). Prior to finalizing the tasks, performance details and errors were defined and several faculty surgeons and a senior surgical resident tested the tasks.

**Task Details**

**Task 1: Bead saucer transfer** requires the transfer of 5 beads from 1 saucer to another with the dominant hand and then back to the original saucer with the non-dominant hand. One dropped bead is allowed; any subsequent drops are errors.

**Task 2: Bead post transfer** requires interns to place 4 beads of the same color onto 1 peg with their dominant hand and then place 4 beads of another color onto a second peg with their non-dominant hand. Two bead drops are allowed; subsequent drops are errors.

**Task 3: Rubber band transfer** requires interns to use their dominant hand to stretch and place 3 rubber bands onto 2 posts then use their non-dominant hand to remove them. Post avulsion is considered an error.

**Task 4: Paper cutting** requires interns to cut a post-it note along standardized markings into 4 equal squares. Any sections cut outside of a blue line is considered an error; 2 errors are allowed.
Task 5: Needle bead transfer requires interns to use a needle grasped in a needle driver to pick up and transfer 5 beads from 1 container to another. One bead drop is allowed; subsequent drops are errors (Fig. 2, Table 2).

Proficiency-based Training Benchmarks

After developing the tasks, we obtained data on how experts performed them. Metrics measured included total time to task completion (completion time) and errors. In order to maintain high training standards, we utilized 3 unpracticed repetitions of an expert fellowship-trained minimally invasive surgeon. Expert-level performance data was then used to determine proficiency-based training benchmarks using previously reported methods: benchmark time (rounded to the nearest second) = expert mean raw score or expert mean raw score + 1 to 2 standard deviations (SD). Suitability of the benchmarks was determined by measuring the unpracticed performance of a senior resident, defined as suitable if the resident achieved near the benchmark on at least 1 of 3 unpracticed attempts.

Scoring formulas were created for each task: cutoff time - completion time - penalty score = score. Cutoff time was the baseline intern performance plus 1 SD. The penalty score was a constant (K) multiplied by the number of errors. The constant was determined by the allowable number of errors until task failure; additional grace for allowable errors was determined by expert unpracticed performance. Higher scores represented better performance. Negative scores were assigned a score of zero. An expert-derived proficiency score was determined for each task by calculating the score from the benchmark time (Table 3).

Finally, a composite score for all 5 tasks was created by taking the sum of each task score normalized to the proficiency score. A composite score of 500 would be equivalent to achieving an overall expert level of performance.

Study Design and Study Population

The study was designed as a single-arm unblinded cohort observational trial. All general surgery interns who matriculated in 2020 participated in the trial, including both categorical and preliminary residents. All interns received the training equipment concurrently and underwent a virtual group orientation to the curriculum at the beginning of their intern year. This included providing an overview of the curriculum structure and an introduction to all of the supplies, task setup, and proficiency benchmarks. Learners were additionally provided a curriculum summary document, which covered all that was discussed in the orientation.

Proficiency-based Training

Interns were then asked to submit individual videos of pre-test performance on each task to the simulation faculty.
and then to practice (on a self-determined schedule) to reach proficiency based on the previously derived benchmarks. After achieving the proficiency benchmarks on all 5 tasks, interns were then asked to submit individual videos of proficient post-test performance to 1 simulation faculty member along with information on the number of repetitions they completed to achieve proficiency.

**Video-based Review and Statistical Analyses**

A single faculty member (D.E.F.) graded all pre-test and post-test videos. Data recorded included total time to task completion, number of errors (errors), and number of repetitions to proficiency (repetitions). The pre-test scores and composite scores were calculated for those who achieved proficiency. Overall descriptive statistics are reported as median (IQR). Construct validity was evaluated by comparing expert scores to intern pre-test scores using a non-parametric Wilcoxon test. Additional paired non-parametric analysis was used to compare the pre- to post-test scores of those who completed the curriculum, in order to assess their skill acquisition. All data were analyzed with RStudio (version 1.3.959), and a p value of <.05 was considered significant.

| Task Name            | Essential Skills Represented                                      | Performance Details                                                                 | Errors                                      |
|----------------------|-------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------|
| Bead saucer transfer | Depth perception, hand-eye coordination, fine object manipulation | Transfer 5 beads from 1 saucer to another with the dominant hand and then transfer them back with the non-dominant hand. | Dropped bead (1 allowable drop)            |
| Bead post transfer   | Depth perception, hand-eye coordination, fine object manipulation | Place 4 beads of the same color onto 1 peg with the dominant hand and then place 4 beads of another color onto a second peg with the non-dominant hand. | Dropped bead (one allowable drop of each color, 2 total) |
| Rubber band transfer | Depth perception, hand-eye coordination, bimanual manipulation/ambidexterity, tension/tactile perception | Use the dominant hand to stretch and place 3 rubber bands onto 2 posts 1 at a time and then use the non-dominant hand to remove them. | Post avulsion                              |
| Paper cutting        | Hand-eye coordination, bimanual manipulation/ambidexterity, precision cutting | Cut a post-it notes along standardized markings into 4 equal squares.               | Rips, sections cut outside of the standardized markings (2 allowable outside cuts, no rips were allowed) |
| Needle bead transfer | Depth perception, hand-eye coordination, fine object manipulation, bimanual manipulation/ambidexterity, tension/tactile perception, instrument and needle handling | Use the tip of a needle grasped in a needle driver to pick up and transfer 5 beads from one saucer to another. | Dropped bead (1 allowable drop)            |

**TABLE 2.** Description of all 5 Tasks, Including Their Essential Skills, Details, and Errors.

| Benchmark Formula | Benchmark Completion Time | Scoring Formula | Expert-Derived Proficiency Score |
|-------------------|--------------------------|-----------------|---------------------------------|
| Task 1: Bead saucer transfer | Expert mean + 2 SDs | 56 | \(180 \times \text{time}\) - \(180 \times (\text{errors} - 1)\) | 124 |
| Task 2: Bead post transfer | Expert mean + 2 SDs | 133 | \(300 \times \text{time}\) - \(300 \times (\text{errors} - 2)\) | 167 |
| Task 3: Rubber band transfer | Expert mean + 2 SDs | 82 | \(180 \times \text{time}\) - \(180 \times (\text{errors})\) | 98 |
| Task 4: Paper cutting | Expert mean + 2 SDs | 119 | \(300 \times \text{time} - 50 \times (\text{errors} - 2)\) | 181 |
| Task 5: Needle bead transfer | Expert mean + 2 SDs | 45 | \(300 \times \text{time} - 300 \times (\text{errors} - 1)\) | 255 |
RESULTS

Expert-derived Proficiency Benchmarks

One expert performed 3 unpracticed repetitions of each task. A comparison of the expert’s performance with the senior resident’s unpracticed attempts showed no significant difference, supporting the suitability of the expert levels (Table 4). The expert’s benchmark times ranged from 45 seconds for task 5 to 133 seconds for task 2. Using the scoring formula, expert-derived proficiency scores were calculated ranging from 98 on task 3 to 255 on task 5. Task 4 suitability was determined at expert mean alone unlike other tasks given the senior resident’s ability to reach near expert level without practice (Table 3).

Study Population

A total of 29 interns (13 categorical, 16 preliminary) submitted pre-test performance videos. Of those, 26 interns (13 categorical, 13 preliminary) submitted post-test performance videos and thereby completed the curriculum. 3 residents did not complete the curriculum due to other clinical priorities, as they were not matriculating to a general surgery residency.

Pre-test Performance Data and Construct Validity Evidence

Baseline performance data (median [IQR]) on each task were as follows: task 1: 36 seconds (0-74); task 2: 96 (36-156); task 3: 86 (65-97); task 4: 0 (0-31); and task 5: 212 (162-237). Of note, some interns (1 intern for task 4, and 6 interns for tasks 2 and 3) achieved proficiency on baseline attempts. One intern achieved proficiency on all 5 tasks at baseline. Significant differences between pre-test intern scores and expert scores were detected for all tasks (Table 5).

Training to Proficiency and Paired Analysis

After 1 month of training, 8/29 or 28% of the interns achieved proficiency on all tasks (6 categorical, 2 preliminary). By 8 weeks into the curriculum, just over half of the residents 15/29 or 52% had achieved proficiency. And by the end of the curricular year, all but 1 resident who completed the curriculum were verified as achieving proficiency (Fig. 3). The 1 resident who did not achieve proficiency had achieved it on all but 1 task in which he was 1 point below the proficiency cutoff. Each task took anywhere from 2 to 18 repetitions during training to reach proficiency. The rubber band task took the fewest attempts with a median of 2, while the bead to peg and precision cutting tasks took a median of 4.5 and 5 attempts, respectively. Composite scores on the pre-test for all residents had a median of 225 seconds (160-329) which rose by post-test to 499 (489-512) (p = 0.01; Fig. 4). A composite score of 477 was equivalent to achieving proficiency. Significant differences were identified in both the pre-test (median 329 vs. 190, p < 0.01) and post-test (median 507 vs. 489, p < 0.01) composite scores.

TABLE 4. Comparison of Unpracticed Expert and Unpracticed Senior Resident Scores. Scores Reflect Completion Time and Errors, With a Higher Score Indicating Superior Performance. The Resident was Able to Meet or Exceed Expert Performance on Task 2, 3, and 5 and Achieved Near-expert Performance on Task 1 and 4.

| Task     | Expert Performance Scores | Senior Resident Performance Scores | p value |
|----------|----------------------------|-----------------------------------|---------|
| Task 1: Bead saucer transfer | 120, 124, 121 | 100, 0, 101 | 0.10 |
| Task 2: Bead post transfer | 175, 172, 186 | 112, 188, 201 | 0.70 |
| Task 3: Rubber band transfer | 74, 88, 90 | 89, 121, 122 | 0.20 |
| Task 4: Paper cutting | 189, 208, 201 | 100, 162, 181 | 0.10 |
| Task 5: Needle bead transfer | 129, 127, 129 | 0, 252, 248 | 0.66 |

TABLE 5. Comparison of Expert Scores and Intern Pre-test Scores were Significantly Different for all 5 Tasks, Providing Evidence in Support of Construct Validity.

| Task       | Expert Score Median (IQR) | Trainee Pre-test Score Median (IQR) | p value |
|------------|---------------------------|------------------------------------|---------|
| Task 1: Bead saucer transfer | 128 [127.5-129.5] | 36 [0-74] | 0.01 |
| Task 2: Bead post transfer | 179 [177.5-184.5] | 96 [36-156] | 0.03 |
| Task 3: Rubber band transfer | 119 [112-120] | 86 [65-97] | 0.04 |
| Task 4: Paper cutting | 201 [195-204.5] | 0 [0-31] | 0.01 |
| Task 5: Needle bead transfer | 256 [255-256] | 212 [162-237] | 0.02 |
scores of categorical versus preliminary interns respectively who completed the curriculum.

**DISCUSSION**

Our study aimed to create a feasible and effective remote laparoscopic skills curriculum to support skill acquisition in novice trainees who matriculated during the COVID-19 pandemic. Interns were provided with at-home training equipment and then self-practiced to reach expert-derived proficiency benchmarks for 5 novel tasks that reflected basic laparoscopic skills. Significant differences in scores between intern pre-test data and expert data were detected for all tasks, supporting construct validity of the assessment metrics. In the previous in-person curriculum, all interns demonstrated proficiency during scheduled proctored sessions in December. With the at-home curriculum, 28% of interns reached proficiency after 1 month of training with fewer than 18 repetitions of each task. This demonstrates the feasibility of expected skill acquisition in a reasonable amount of time and repetitions. Furthermore, skill acquisition was supported by the convergence of composite scores in those who met proficiency, despite the high variability of pre-test scores (Fig. 3).

Given evidence in previous literature, we were not surprised by the ability of our residents to obtain skill matching proficiency-based benchmarks. We were, however, impressed that the benchmarks were met by some of them relatively rapidly despite ongoing normal clinical duties. Despite comparison to a different curriculum, the ability to self-train at home and to also submit self-made videos for video-based assessment shows earlier proficiency confirmation if not evidence of attaining proficiency abilities earlier. This further cements the benefits of accessible and self-determined practice with remote training resources and the decreased burden of faculty involvement when comparing video-based assessment to proctored in-person post-tests. Furthermore, after achieving proficiency, 4 interns have registered for the FLS examination and 1 has taken and passed it despite no additional structured suturing or endoloop training. This may be in part due to familiarity to other FLS tasks as supplies such as the peg board and circle cut were also included in the kits for self-practice. This is the first time our institution has had interns register and take the examination, reflecting their comfort and skill after completion of our curriculum.

Overall, our curriculum fills the aforementioned gap in demonstrating the feasibility of at-home training that focuses on skill acquisition for novice learners using an expert-derived proficiency-based curriculum associated with construct validity evidence. Since its roll-out, other more senior residents have requested access to the training equipment and curriculum as well.

We acknowledge certain limitations in our study design, including its lack of randomization and small sample size. Proficiency benchmarks, construct validity, and baseline feasibility analysis were based off of a single minimally invasive trained expert and senior resident given time and social distancing constraints preventing the recruitment. Additionally, a confounding factor that may have affected our data is the grouping of preliminary non-departmental interns (e.g., radiology or anesthesia interns) with categorical and preliminary general surgery interns during data analysis. Despite the lack of a control group, which we omitted to provide fair and equal training across all novices.
during the pandemic, the strength of our study is that it shows that remote practice can provide necessary training using low-cost equipment over a reasonable amount of time while ensuring the convergence of skill acquisition to the level of an expert. Our curriculum further demonstrates an easily achievable proficiency-based framework that can be applied to task development across a variety of low-fidelity at-home trainers by other institutions and specialties. Additionally, this framework can remain consistent while adapting its task complexity or difficulty for different levels of trainees. In the future, as we anticipate resuming normal practice after the pandemic, we may consider still using this remote curriculum, given its advantages. We may also evaluate whether a remote proficiency-based curriculum produces skill retention and transferability to the operating room, further supporting its role in ongoing surgical education. Remote learning with video capture also allows easier access to remote coaching, learning curve assessment, and many other video-based technologies.

**CONCLUSIONS**

This study shows that at-home laparoscopic skills training for novice learners is not only feasible but also efficient, requiring a reasonable amount of time and repetitions to obtain skills without being too easy or frustrating for learners. Additionally, we provide evidence of construct validity on all 5 tasks which supports the use of proficiency-based training. We conclude that our at-home laparoscopic training curriculum and its remote teaching and video-based assessment is effective and relevant for our ongoing needs.

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None.

**MEETING PRESENTATION**

Presented as a poster at the Virtual Surgical Simulation Summit of the American College of Surgeons Accredited Educational Institution on March 11 to 12, 2021

**DISCLOSURE**

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article. Benchmark time and score as listed below: benchmark time = expert mean raw score or expert mean raw score +1 to 2 standard deviations, score = cutoff time - completion time - (K \times \text{number of errors}).

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**MATH FORMULAE**

Score = cutoff time - completion time - (K \times \text{number of errors}).

**DECLARATIONS OF INTEREST**

None.

**CONTRIBUTIONS**

Madhuri B. Nagaraj: curriculum design, data collection, data analysis and manuscript creation, manuscript approval; Kareem R. Abdelfattah: curriculum design, manuscript editing, manuscript approval; Daniel J. Scott: curriculum design, data analysis, manuscript editing, manuscript approval; Deborah E. Farr: curriculum design, data collection, video-based review, data analysis, manuscript editing, manuscript approval.

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