

A competency-based laparoscopic cholecystectomy curriculum significantly improves general surgery residents' operative performance and decreases skill variability

Cohort study

Elizabeth M. Huffman, MD^a; Jennifer N. Choi, MD^a; John R. Martin, MD^a; Nicholas E. Anton, MS^a; Brianne L. Nickel, MA^a; Sara Monfared, MD^a; Lava R. Timsina, MPH, PhD^a; Gary L. Dunnington, MD^a; Dimitrios Stefanidis MD, PhD^a

Indiana University School of Medicine, Department of Surgery, Indianapolis, IN

Address correspondence concerning the manuscript and requests for reprints to: Dimitrios Stefanidis, MD, PhD, FACS, FASMBS

Vice Chair of Education, Department of Surgery

Indiana University School of Medicine

545 Barnhill Drive

Emerson Hall 130

Indianapolis, IN 46202

Phone: (317) 278-2304

Fax: (317) 274-8769

Email: dimstefa@iu.edu

Conflicts of Interest and Source of Funding

This project was made possible by Indiana University Health and the Indiana Clinical and Translational Sciences Institute, funded in part by grant #UL1 TR002529 from the National Institutes of Health, National Center for Advancing Translational Sciences, Clinical and Translational Science Award and The Advances in Medicine (AIM) grant from Cook Medical. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or Cook Medical.

Lap Chole Competency Curriculum

Contributions of Individual Authors

Please see the following for a brief justification of each author's contribution to the manuscript:

Elizabeth M. Huffman – conception and design, acquisition of data, data analysis and interpretation

Jennifer N. Choi – conception and design, interpretation of data

John R. Martin – conception and design, acquisition of data, interpretation of data

Nicholas E. Anton – conception and design, acquisition of data, interpretation of data

Brianne L. Nickel – conception and design, acquisition of data

Sara Monfared – acquisition of data, interpretation of data

Lava R. Timsina – data analysis and interpretation

Gary L. Dunnington – conception and design, interpretation of data

Dimitrios Stefanidis – conception and design, interpretation of data

All of the authors listed above participated in the drafting of the paper as well as critical revisions and gave their final approval of the submitted version to be published.

Structured Abstract

Objective

To demonstrate the feasibility of implementing a competency-based education (CBE) curriculum within a general surgery residency program and to evaluate its effectiveness in improving resident skill.

Summary Background Data

Operative skill variability affects residents and practicing surgeons and directly impacts patient outcomes. CBE can decrease this variability by ensuring uniform skill acquisition. We implemented a CBE laparoscopic cholecystectomy (LC) curriculum to improve resident performance and decrease skill variability.

Methods

PGY-2 residents completed the curriculum during monthly rotations starting in July 2017. Once simulator proficiency was reached, residents performed elective LCs with a select group of faculty at three hospitals. Performance at curriculum completion was assessed using LC simulation metrics and intraoperative OPRS scores and compared to both baseline and historical controls, comprised of rising PGY-3s, using a two-sample Wilcoxon rank-sum test. PGY-2 group's performance variability was compared with PGY-3s using Levene's Robust Test of Equality of Variances; $p < 0.05$ was considered significant.

Results

21 residents each performed 17.52 ± 4.15 consecutive LCs during the monthly rotation. Resident simulated and operative performance increased significantly with dedicated training and reached that of more experienced rising PGY-3s ($n=7$) but with significantly decreased variability in performance ($p=0.04$).

Conclusions

Completion of a CBE rotation led to significant improvements in PGY-2 residents' LC performance that reached that of PGY-3s and decreased performance variability. These results support wider implementation of CBE in resident training.

Mini-abstract

A competency-based curriculum for laparoscopic cholecystectomy was created. Completion of the curriculum led to significant improvements in PGY-2 residents' simulated and operative performance that reached that of PGY-3s and displayed decreased performance variability. These results support wider implementation of competency-based education in surgical resident training.

INTRODUCTION

The traditional, time-based paradigm for training surgery residents—in which residents complete five years of pre-determined clinical rotations—is characterized by unpredictable exposure to pathologies and procedures which challenges the consistency of experience individual residents get during their training.^{1,2} Indeed, concerns have been voiced by trainees, program directors, and surgical education leaders alike that the inconsistent training experience that characterizes this training paradigm leads to inadequate skill acquisition by residents.^{3,4} Supporting these concerns are the results of a multi-institutional study which demonstrated significant performance variability within postgraduate year (PGY) levels of general surgery residents in the simulated environment.⁵ This performance variability has also been demonstrated in the operative skill of practicing surgeons and has been shown to significantly correlate with patient outcomes.⁶ This issue is appropriately heightened by an emphasis on patient safety that further limits the operating room exposure of residents.⁷ Additionally, technological advances and the introduction of minimally invasive surgical techniques into the surgical armamentarium pose new challenges to technical skill acquisition as residents are required to master a variety of modalities and approaches to surgical diseases.⁸ Critics reiterate that traditional training has failed to adapt, resulting in the delayed acquisition (or worse, the non-acquisition) of necessary technical abilities among surgery trainees.^{2,4}

Competency-based education (CBE) can ease these concerns and decrease variability by ensuring uniform skill acquisition given its fundamental organization around curricular outcomes.² In the current time-based training paradigm, residents' random exposure to cases does not guarantee that residents will receive the level of experience needed to achieve competence.⁹ Conversely, in a competency-based paradigm, all residents must meet pre-defined minimum performance standards prior to progression to the acquisition of new skills and procedures.¹⁰ For this reason, CBE has been heralded as having the “potential to transform contemporary medical education”.² Major international medical accrediting organizations now require competency-based assessments. The Accreditation Council for Graduate Medical Education (ACGME) Common Program Requirements specify that residency programs must provide objective, competency-based performance assessments to inform resident progression toward unsupervised practice.¹¹ Notably, the Royal College of Physicians and Surgeons in Canada introduced the Competence by Design initiative requiring all residency training programs in Canada to transition to CBE, with general surgery launching their CBE programs in July of 2020.¹² Inspiring this transition, the orthopedic surgery residency program at the University of Toronto developed a CBE training pathway in 2009, which has received positive feedback from faculty and trainees, resulted in increased flexibility in training pathways, and even shortened time to graduation for some residents.¹³

Nevertheless, a true CBE training paradigm has yet to be implemented in a US general surgery residency program, and the feasibility and effectiveness of this approach remains unknown. To address this need, we embarked into the development and implementation of a pilot procedural CBE rotation focused on one of the most commonly

performed general surgical procedures, the laparoscopic cholecystectomy. Our aim was to assess the feasibility of implementing a CBE procedural curriculum within the constraints of a busy general surgery residency program and to evaluate its effectiveness in improving resident skill. We hypothesized that the implementation of a CBE curriculum would improve resident operative performance and decrease their skill variability compared to traditionally trained peers.

METHODS

Curriculum Design

The conceptual framework for our IRB approved CBE curriculum was based on the principles proposed by the International Competency Based Medical Education (ICBME) Collaborators. The main principles of CBE are the following: focusing on outcomes, emphasizing abilities, de-emphasizing time-based learning, and promoting greater learner-centeredness.²

We used Kern's six step approach to develop our CBE curriculum.^{2, 14} Problem identification and general needs assessment were rooted in the background literature and expert opinion regarding CBE as the current ideal approach for residency training. In a 2004 study conducted by the American Board of Surgery (ABS), laparoscopic cholecystectomy (LC) was identified as not only one of the essential procedures in which general surgery residents should be competent performing prior to graduation, but it may in fact be the quintessential procedure.³ LC is the single-most commonly performed operation in general surgery, and it was the only procedure on the ABS list of 121 essential procedures for which residents performed an average of more than 50 repetitions.³ Despite this, when looking at resident performance of six core general surgery procedures, Larson *et al* observed the greatest performance variation was seen among trainees performing laparoscopic cholecystectomies.¹⁵ Therefore, we sought to develop our CBE curriculum around the LC in order to ensure feasibility and translatability of our curriculum.

Our subsequent targeted needs assessment identified PGY-2 residents as the optimal stage of training for our intervention. Institutional resources were also assessed at this stage, including identification of faculty to assist in the curriculum and an appraisal of service case volume to ensure feasibility. Goals and objectives were created in alignment with ACGME milestones for general surgery (see Document, Supplemental Digital Content 1 <http://links.lww.com/SLA/C996>, which outlines rotation goals and objectives).^{16, 17} Educational strategies selected included deliberate practice, simulation, and provision of detailed performance feedback. Resources for medical knowledge improvement were identified including the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) Safe Cholecystectomy Program and readings on biliary disease from the American Board of Surgery Surgical Council on Resident Education (SCORE) curriculum.^{18, 19} Assessments most suited to our educational strategies and in alignment with our goals and objectives were then selected for use in our curricular assessment battery. These consisted of

a short-answer knowledge test, the imbedded metrics within the LAP Mentor virtual reality (VR) simulator (3D Systems, formerly Simbionix, Rock Hill, SC), and the Operative Performance Rating System (OPRS), a multiple-item procedure-specific assessment with validity evidence that uses a 5-point Likert scale with descriptive anchors.¹⁵ Specifically, the eight imbedded recorded metrics within the LAP Mentor VR simulator were total time, time to extract the gallbladder, efficiency of cautery, number of perforations, number of non-cauterized bleeding, number of serious complications, total number of movements, and total path length. The ten OPRS assessment questions included ratings of incision/port placement, exposure, cystic duct dissection, cystic artery dissection, gallbladder dissection, instrument handling, respect for tissue, time and motion, operation flow, and overall performance. The OPRS level of 3 (“good”) was selected as our competency benchmark. An additional operative performance question regarding the resident’s independent attainment of the critical view of safety (CVS) with a binary yes/no response option was included. The resident’s ability to independently achieve the CVS was assessed by the attending prior to division of the cystic duct and artery, or earlier if the attending needed to take over the case in order to safely complete the dissection.

Prior to the start of the curriculum, the ten participating surgical faculty members were trained in the use of the OPRS assessment and reviewed the goals and objectives of the curriculum, particularly that of attainment of the CVS. Participating surgical faculty agreed to perform laparoscopic cholecystectomies in alignment with the SAGES Safe Cholecystectomy Program in order to provide standardization for the residents.¹⁹ Faculty were also taught to facilitate residents’ deliberate practice by providing immediate, meaningful feedback.

Curriculum Implementation

The Indiana University Laparoscopic Cholecystectomy Curriculum (IU LCC) officially began on July 1, 2017 with PGY-2 residents completing the month-long rotation one at a time (Figure 1). Each rotation started with the resident completing the assessment battery, which included a written knowledge test, completing a VR LC in the simulation lab, and performing an operative LC assessed by a trained faculty rater using the OPRS scale and CVS question. Residents then underwent deliberate, proficiency-based training in the simulation lab on both the Fundamentals of Laparoscopic Surgery (FLS) task trainer (Limbs & Things, Inc., Savannah, GA) and the LAP Mentor simulator. Once expert-derived simulator metrics were reached on both platforms, residents progressed to performing elective operative LCs across the IU Health system under direct supervision of trained faculty surgeons.^{1, 20} Elective LCs were defined as planned outpatient procedures in patients without a body mass index (BMI) >50, severe cirrhosis, or multiple prior abdominal surgeries. Concurrent to the proficiency-based training in the simulation lab and the operative elective LCs, residents reviewed the provided videos and readings in order to improve their understanding of the procedure and biliary disease knowledge. Residents also rehearsed mental skills as part of an ongoing effort within the IU School of Medicine Department of Surgery to employ mental imagery techniques in order to enhance skill acquisition.^{8, 21-26} Additionally, each resident met with a surgical faculty coach to go over one of their own recorded LCs in order to identify

individual performance strengths and areas for improvement. At the end of the month, resident performance was assessed with the same assessment battery used at the beginning of the rotation. Residents completed an end of rotation evaluation once all curricular components were accomplished which consisted of questions on a 4-point Likert scale (strongly disagree to strongly agree) as well as free response questions regarding the strengths and weaknesses of the curriculum.

Simulated and operative performance at curriculum baseline was compared to post curriculum performance using a two-sample Wilcoxon rank-sum test. Post curriculum performance was also compared to historical controls using a two-sample Wilcoxon rank-sum test. Historical controls included residents in their PGY-3 year who completed the same curricular assessment battery during July-August of 2017 (i.e. at the beginning of their PGY-3 training in the traditional paradigm). Average months in residency at time of the assessment was calculated for both the curriculum and historical control groups as well as the average number of LCs performed at the time of each of the assessments. We also recorded and compared the length of time it took historical control residents to complete the same amount of LC cases that curriculum residents completed during their monthly rotation. ACGME milestones for both cohorts were reviewed to evaluate for global deficiencies in technical performance. Resident improvement on the written knowledge test from baseline to post curriculum was calculated using a paired t-test. Resident independent attainment of the CVS based on attending judgement during the post curriculum operative LC was compared to that of historical controls using Fisher's exact test. Post curriculum performance variability for the curriculum group was compared to historical controls using Levene's Robust Test of Equality of Variances, which assesses the assumption that variance of populations from which different samples are drawn are equal; $p < 0.05$ was considered significant. All analyses were done using Stata/SE 14.2 (StataCorp LLC, College Station, TX).

RESULTS

Twenty-one residents (12 males and 9 females) completed the IU LCC. Residents participating in the curriculum had completed a mean \pm standard deviation of 17.76 \pm 3.56 months of residency prior to the start of the rotation while the seven historical control residents (4 males and 3 females) had completed 24.29 \pm 0.49 months of residency at the time of their testing ($p < 0.01$). Curricular residents had performed an average of 15.81 \pm 6.63 LCs prior to their CBE rotation and completed another 17.52 \pm 4.15 LCs during the rotation for a total of 33.33 \pm 7.37 LCs by the end of the monthly CBE rotation. Historical control residents had completed an average of 34.43 \pm 6.83 LCs at the time of their testing, which was not significantly higher than the final curricular group LC case numbers ($p = 0.73$). It took 10.88 \pm 3.40 months for the historical control residents to complete the same number of LCs ($n = 18$) that the curriculum group completed within their 1-month rotation ($p < 0.001$). There were no ACGME milestone differences or other documented deficiencies in global technical performance between the two cohorts.

Resident performance on the simulated LC significantly improved on all but one of the eight performance variables measured, and operative LC performance improved significantly on seven of the ten measured performance variables (Table 1). Curriculum residents attained the CVS on 100% of their post curriculum operative LCs, compared with 71% of the historical controls ($p=0.056$). While no significant difference in performance was found between PGY-2 residents post curriculum and PGY-3 historical controls (Table 1), performance variability from resident to resident was significantly lower in the curriculum group ($p=0.04$; Figure 2).

Resident performance on the written knowledge test improved by an average of 9% (baseline 49.3%, post curriculum 58.3%, $p<0.001$). End of rotation evaluations demonstrated that 59% of curriculum residents agreed strongly with the statement “I gained independence in performing the lap chole procedure over the course of the rotation” and 73% agreed strongly that the rotation allowed them to “Participate in surgical operations with attending supervision”. Identified weaknesses mainly noted logistical issues encountered with the various technological platforms used at each hospital as well as navigating the remaining variation in attendings’ operative approaches. Residents identified many strengths of the curriculum, including an increase in operative confidence as well as dedicated time for deliberate practice in the simulation lab. Representative quotes can be found in Table 2.

DISCUSSION

We were able to successfully create and implement a CBE curriculum in a busy general surgery residency program. Participation in the CBE curriculum led to significant improvement in PGY-2 resident simulated and operative LC performance, allowing them to reach the level of traditionally trained PGY-3s by accelerating their skill acquisition. Importantly, the CBE curriculum ensured uniform skill acquisition with no resident scoring below the competency benchmark of 3 (“good”) on the OPRS scale while 2 of 7 (28.5%) of historical control PGY-3 residents had scored a 2 (“fair”). Evidence for this uniformity is additionally provided by the decreased performance variability curriculum residents demonstrated compared to historical controls. The IU LCC also improved safety in resident operative performance with all curriculum residents attaining the CVS during their post curriculum assessment compared with 71% of historical controls. Further, curriculum residents reported increased confidence in their laparoscopic skills as a result of the curriculum as well as increased autonomy in the operating room.

The observed benefits are likely the result of the focused, concentrated, and deliberate practice of the same procedure that allowed residents to accelerate their learning curve. Deliberate practice has been shown to benefit performance in many ways, including leading to decreased individual performance variability, which is considered a marker of expert performance.²⁷⁻²⁹ Deliberate practice has also been shown to decrease group performance variability, as observed in our study, which in the context of CBE, ensures educators that their learners are consistently able to reach competent performance.^{28, 30} Our findings compare favorably to the well-described experience of the orthopedic surgery residency

program at the University of Toronto; their CBE group was also able to perform technical skills at the level of more senior traditionally trained residents.^{4, 13, 31} The Toronto curriculum also decreased the time to graduation for some trainees; given that we were able to deliver a concentrated LC case experience over 1 month that took traditionally trained residents over 10 months to obtain, we were also able to demonstrate decreased time required to train residents to an equivalent level of performance.¹³ This accelerated skill acquisition has many benefits, including the ability to offer more advanced technical opportunities for residents elsewhere in their residency training, as well as the dedication of more time for focused career exploration.

Creation and implementation of a CBE curriculum encountered expected challenges given the many complex factors at play in today's residency training. Challenges included logistical considerations and obtaining buy in from faculty and residents. While our institution has a strong culture of excellence in surgical education, this new curriculum required a higher level of active participation on the part of faculty and residents. Several faculty development sessions were held to impart the theory behind our CBE curriculum, to confirm standardized LC techniques, to teach accurate use of assessment tools, and to discuss program evaluation methods. Resident buy in was required from both traditionally trained senior residents and curricular residents. Given the shift in elective LC case volume, we ensured that this change would not be detrimental to our senior residents by verifying resident case numbers prior to curriculum implementation and by reserving non-elective LCs for the more senior residents. Ultimately, the elective LC case volume was effectively redistributed from across the PGY2 year into a concentrated experience during the rotation. This redistribution allowed for the senior resident LC case volume to remain unaffected. Curriculum resident buy in was also necessary as our CBE curriculum is largely resident-directed; it is the responsibility of the residents to select which elective LCs they would perform each week, video-record their own cases, initiate faculty assessments, and schedule coaching practice sessions. Compliance with these requirements has become progressively easier to maintain as more residents complete the curriculum and its benefits become evident in their own performance and the performance of their colleagues.

We were able to successfully design and implement an effective CBE curriculum by ensuring that it was rooted in the conceptual framework of the main principles of CBE: focusing on outcomes, emphasizing abilities, de-emphasizing time-based learning, and promoting greater learner-centeredness.² First and foremost CBE is “organized around competencies, or predefined abilities, as outcomes of the curriculum.”² As part of our focus on outcomes, we were especially deliberate in our selection of curriculum assessments, ultimately choosing those that best aligned with our goals and objectives, and had high quality validity evidence supporting their use. In order to emphasize abilities, we selected primarily performance-based assessments and added several multimodal adjuncts to training including mental skills rehearsal, one-on-one video review with a faculty coach, and placed a strong emphasis on deliberate practice throughout the curriculum. Although the overall curriculum remains time-bound at this point given currently inflexible system needs such as the resident call schedule, we strove to de-emphasize time-based learning by allowing the

residents as much time in the simulation lab as needed in order to reach the pre-defined proficiency benchmarks prior to progression to the operating room. Finally, we promoted greater learner-centeredness by designing the majority of the curriculum to be self-directed.

As part of our ongoing curriculum evaluation process, we have implemented several additional curricular enhancements in response to resident and faculty feedback. Given the large number of faculty coaches, residents expressed the desire to have a way to familiarize themselves with the nuances of each faculty's surgical techniques in order to maximize their learning time in the operating room. While all the faculty coaches guided residents to perform LCs in alignment with the SAGES Safe Cholecystectomy Program, they varied in their selection and use of surgical instruments. We have therefore provided recordings of LCs which best demonstrates each faculty's techniques for resident review prior to working with the respective faculty coach. Other new curricular adjuncts include an increase in the faculty one-on-one video review coaching sessions from monthly to weekly, an overview of laparoscopic instruments, a cholangiogram module including simulation, and the inclusion of an autonomy assessment using the Zwisch scale delivered via the SIMPL application.³² Additionally, after review of our knowledge test results, we identified both construct irrelevant variance and construct underrepresentation present in the initial version of the assessment. We therefore designed a new multiple-choice test in better alignment with our goals and objectives for the rotation. While we have not needed to remediate any residents to date, CBE requires remediation if benchmarks are not met. Our remediation policy for this curriculum centers on extending the CBE assessment process. If resident curriculum performance were to be borderline, this assessment would occur on subsequent rotations in which residents still perform elective LCs. If resident performance were to be poor and extensive remediation needed, the curriculum would be repeated. Given the success of this curriculum, we are working to engage other residency programs to implement this curriculum and are working on the creation of other CBE modules with the goal of transitioning to an entirely CBE residency program.

Our study, like every project, has some limitations. Our intervention was not randomized, and we used early PGY-3s as historical controls which introduced bias in our results. Nevertheless, while we entertained implementing the curriculum in a randomized fashion at the beginning, ultimately, we did not feel it was ethical to withhold it from any eligible resident in order to obtain a more appropriate control group. In addition, the Toronto group's experience with the implementation of their CBE curriculum helped inform this decision. Even though their curriculum was initially offered to a proportion of their residents they transitioned to an entirely CBE residency after only four years due to the profound benefits seen in many aspects of the CBE pathway.^{4, 13} Our curriculum was also focused on the technical performance of laparoscopic cholecystectomy and did not embed clinical experience with the preoperative workup of patients with gallbladder disease or postoperative follow up since our residents received ample opportunities for perioperative care of patients with biliary disease on several other rotations. We have now added a required clinic experience with our faculty coaches during this rotation to address this limitation and enhance the nontechnical aspects our curriculum.

To our knowledge, this is the first application of CBE in a US general surgery residency program. Completion of our CBE rotation led to significant improvements in PGY-2 residents' simulated and operative LC performance that reached the level of PGY-3s and decreased residents' performance variability. Residents safely and uniformly reached competency after completion of our CBE curriculum. Moving forward, we plan to apply the lessons learned during the creation and implementation of this curriculum towards the development of more competency-based modules within our residency program. Ultimately, these results demonstrate the feasibility of CBE in general surgery and support wider implementation of CBE in resident training.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Tomoko Mizota for her assistance with the assessment process and all of our talented staff surgeons without whom we could never have implemented this curriculum: Dr. Ambar Banerjee, Dr. Christopher Bearden, Dr. Jeffery Brown, Dr. Claire Burgardt, Dr. Annabelle Butler, Dr. Jenalee Cooksey, Dr. Steven Mong, and Dr. Larry Stevens.

REFERENCES

1. Aggarwal R, Crochet P, Dias A, et al. Development of a virtual reality training curriculum for laparoscopic cholecystectomy. *Br J Surg* 2009; 96(9):1086-1093.
2. Frank JR, Snell LS, Cate OT, et al. Competency-based medical education: theory to practice. *Med Teach* 2010; 32(8):638-645.
3. Bell RH, Jr., Biester TW, Tabuenca A, et al. Operative experience of residents in US general surgery programs: a gap between expectation and experience. *Ann Surg* 2009; 249(5):719-724.
4. Ferguson PC, Kraemer W, Nousiainen M, et al. Three-year experience with an innovative, modular competency-based curriculum for orthopaedic training. *J Bone Joint Surg Am* 2013; 95(21):e166.
5. Stefanidis D, Grewal H, Paige JT, et al. Establishing technical performance norms for general surgery residents. *Surg Endosc* 2014; 28(11):3179-3185.
6. Birkmeyer JD, Finks JF, O'Reilly A, et al. Surgical skill and complication rates after bariatric surgery. *N Engl J Med* 2013; 369(15):1434-1442.
7. George BC, Bohnen JD, Williams RG, et al. Readiness of US General Surgery Residents for Independent Practice. *Ann Surg* 2017; 266(4):582-594.
8. Arora S, Aggarwal R, Sirimanna P, et al. Mental practice enhances surgical technical skills: a randomized controlled study. *Ann Surg* 2011; 253(2):265-270.
9. Malangoni MA, Biester TW, Jones AT, et al. Operative experience of surgery residents: trends and challenges. *J Surg Educ* 2013; 70(6):783-788.
10. Huffman EM, Martin JR, Stefanidis D. Teaching technical surgery. *Surgery* 2020; 167(5):782-786.
11. Accreditation Council for Graduate Medical Education. ACGME Common Program Requirements (Residency) 2019. Available at: <https://www.acgme.org/Portals/0/PFAssets/ProgramRequirements/CPRResidency2019.pdf>. Accessed September 3, 2019.
12. Royal College of Physicians and Surgeons of Canada. Competence by Design Launch Schedule 2019. Available at: <http://www.royalcollege.ca/rcsite/cbd/cbd-implementation-e>. Accessed December 19, 2019.
13. Nousiainen MT, Mironova P, Hynes M, et al. Eight-year outcomes of a competency-based residency training program in orthopedic surgery. *Med Teach* 2018:1-13.

14. Kern DE, Thomas, P. A., Huges, M. T. Curriculum development for medical education: a six-step approach. Baltimore: Johns Hopkins University Press, 2009.
15. Larson JL, Williams RG, Ketchum J, et al. Feasibility, reliability and validity of an operative performance rating system for evaluating surgery residents. *Surgery* 2005; 138(4):640-647; discussion 647-649.
16. Accreditation Council for Graduate Medical Education. The Milestones Guidebook 2016. Available at: <https://www.acgme.org/Portals/0/MilestonesGuidebook.pdf>. Accessed June 6, 2019.
17. The Accreditation Council for Graduate Medical Education. Surgery Milestones January 2019. Available at: <https://www.acgme.org/Portals/0/PDFs/Milestones/SurgeryMilestones2.0.pdf?ver=2019-01-31-111438-910>. Accessed May 28, 2019.
18. Surgical Council on Resident Education. SCORE Curriculum Outline for General Surgery 2018-2019. Available at: http://www.absurgery.org/xfer/curriculumoutline2018-19_book.pdf. Accessed June 4, 2019.
19. Society of American Gastrointestinal and Endoscopic Surgeons. The SAGES Safe Cholecystectomy Program. Available at: <https://www.sages.org/safe-cholecystectomy-program/>. Accessed December 17, 2019.
20. Ritter EM, Scott DJ. Design of a proficiency-based skills training curriculum for the fundamentals of laparoscopic surgery. *Surg Innov* 2007; 14(2):107-112.
21. Anton NE, Mizota T, Timsina LR, et al. Attentional selectivity, automaticity, and self-efficacy predict simulator-acquired skill transfer to the clinical environment. *Am J Surg* 2019; 217(2):266-271.
22. Anton NE, Mizota T, Whiteside JA, et al. Mental skills training limits the decay in operative technical skill under stressful conditions: Results of a multisite, randomized controlled study. *Surgery* 2019;165(6):1059-1064.
23. Anton NE, Beane J, Yurco A, et al. Mental skills training effectively minimizes operative performance deterioration under stressful conditions: Results of a randomized controlled study. *Am J Surg* 2018; 215:214–221.
24. Stefanidis D, Anton NE, Howley LD, et al. Effectiveness of a comprehensive mental skills curriculum in enhancing surgical performance: Results of a randomized controlled trial. *Am J Surg* 2017; 213(2):318-324.

25. Stefanidis D, Anton NE, McRary G, et al. Implementation results of a novel comprehensive mental skills curriculum during simulator training. *Am J Surg* 2017; 213(2):353-361.
26. Arora S, Aggarwal R, Sevdalis N, et al. Development and validation of mental practice as a training strategy for laparoscopic surgery. *Surg Endosc* 2010; 24(1):179-187.
27. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med* 2004; 79(10 Suppl):S70-81.
28. Martin JR, Anton N, Timsina L, et al. Performance variability during training on simulators is associated with skill transfer. *Surgery* 2019;165(6):1065-1068.
29. Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. *Acad Med* 2015; 90(11):1471-1486.
30. Stelmach GE. Distribution of practice in individual differences and intra-variability. *Percept Mot Skills* 1968; 26(3):727-730.
31. Sonnadara RR, Garbedian S, Safir O, et al. Orthopaedic Boot Camp II: examining the retention rates of an intensive surgical skills course. *Surgery* 2012; 151(6):803-807.
32. Procedural Learning and Safety Collaborative. About SIMPL 2020. Available at: <https://www.procedurallearning.org/simpl/about-simpl>. Accessed May 11, 2020.

Figure 1. Indiana University Laparoscopic Cholecystectomy Curriculum (IU LCC) Overview

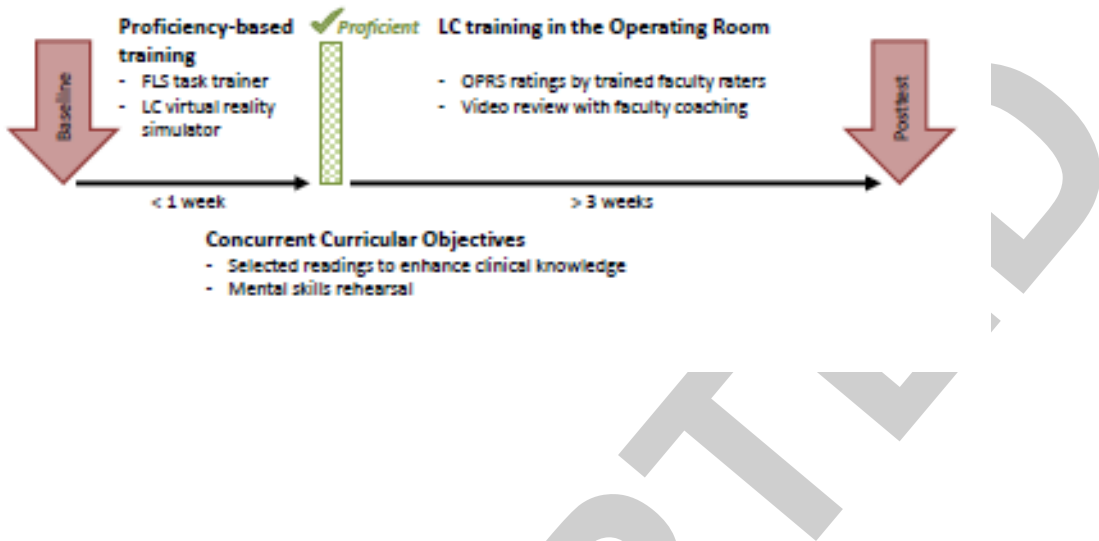


Figure 2. Performance variability of historical controls and curriculum group using OPRS overall performance scores. Circles represent individual resident scores, diamonds represent group median scores, and black lines represent the range of scores for each group.

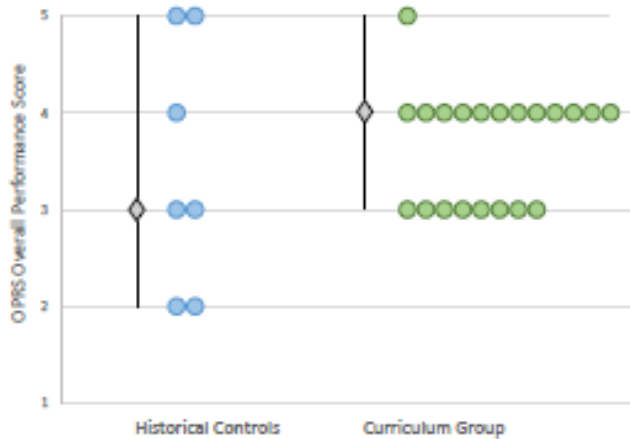


Table 1. Simulated and operative LC performance results for the curriculum group and historical controls. *Denotes significant p-value <0.05.

Assessment	Assessment Variable	PGY-2 baseline mean □ SD	PGY-2 posttest mean □ SD	p-value (baseline vs. posttest)	PGY-3 (historical controls) mean □ SD	p-value (PGY-2 posttest vs. PGY-3)
Simulated LC VR Metrics	Total Time (min)	17.53 □ 5.21	8.76 □ 2.63	<0.01*	8.48 □ 2.82	0.83
	Time to Extract GB (min)	16.61 □ 5.74	8.30 □ 2.51	<0.01*	8.08 □ 2.82	0.90
	Efficiency of Cautery (%)	50.33 □ 13.99	62.55 □ 11.27	<0.01*	57.53 □ 6.28	0.11
	Number of Perforations	5.96 □ 4.89	1.35 □ 2.23	<0.01*	3.29 □ 3.25	0.16
	Number of non-cauterized bleeding	1.00 □ 1.65	0.39 □ 0.66	0.22	0.57 □ 0.98	0.83
	Number of serious complications	1.30 □ 2.4	0.22 □ 0.67	0.04*	0.14 + 0.38	0.97
	Total number of movements	1060.3 □ 313.83	585.17 □ 161.68	<0.01*	629.86 □ 207.03	0.54
	Total path length	2210.77 □ 538.02	1137.85 □ 364.49	<0.01*	1128.22 □ 598.29	0.86
Operative Performance Rating System (OPRS)	Incision/Port placement	3.60 □ 0.94	4.19 □ 0.75	0.03*	4.43 □ 0.98	0.33
	Exposure	1.85 □ 1.42	3.33 □ 0.91	<0.01*	3.71 □ 0.76	0.42
	Cystic Duct Dissection	2.35 □ 1.57	3.71 □ 0.64	<0.01*	4.00 □ 1.15	0.32
	Cystic Artery Dissection	2.30 □ 1.45	3.81 □ 0.60	<0.01*	3.57 □ 1.90	0.50
	Gallbladder	3.25 □ 1.11	3.86 □ 0.65	0.07	3.71 □	0.73

Dissection				11.25	
Instrument Handling	3.20 \square 0.77	3.48 \square 0.68	0.20	3.71 \square 10.95	0.68
Respect for Tissue	3.65 \square 0.75	4.00 \square 0.63	0.09	3.71 \square 10.95	0.33
Time and Motion	2.85 \square 0.75	3.43 \square 0.60	0.01*	3.29 \square 1.11	0.68
Operation Flow	2.90 \square 0.72	3.48 \square 0.60	0.01*	3.57 \square 0.98	0.68
Overall Performance	2.95 \square 0.69	3.67 \square 0.58	<0.01*	3.43 \square 1.27	0.55

Simulated and operative LC performance results for the curriculum group and historical controls. *Denotes significant p-value <0.05.

Table 2. Representative quotes of IU LCC strengths and weaknesses from resident post curriculum evaluations.

Curriculum Strengths
“I really liked this rotation, I felt that it gave me the opportunity to really improve my laparoscopic skills. I feel that the skill set that I was able to develop on this rotation will benefit me going forward, not just in performing lap choles but, in performing laparoscopic procedures in general. I like the flexibility with the rotation, allowing for more dedicated time spent in the skills lab.”
“The repetition of a single procedure certainly increases independence and comfort with the procedure. I feel MUCH better about doing a lap chole now.”
“I cannot begin to compliment enough this rotation on how much more confident I am in performing lap choles, recognizing difficult gallbladders that are above my level, and in my technical skills. This was my favorite rotation thus far of residency.”
Curriculum Weaknesses
“It can be frustrating going from one attending to the next, learning one technique for the operation in one case and then an hour later, being told not to do it that way by a different attending.”
“I think the video aspect could be improved on, many comparisons are drawn between athletics and surgery and film sessions is a big part of sports. Taking advantage of video replay and going over operations with a coach seems like an area that could be explored more.”

Representative quotes of IU LCC strengths and weaknesses from resident post curriculum evaluations.