Designing a proficiency-based, content validated virtual reality curriculum for laparoscopic colorectal surgery: A Delphi approach

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Background. *Although task training on virtual reality (VR) simulators has been shown to transfer to the operating room, to date no VR curricula have been described for advanced laparoscopic procedures. The purpose of this study was to develop a proficiency-based VR technical skills curriculum for laparoscopic colorectal surgery.*
Methods. *The Delphi method was used to determine expert consensus on which VR tasks (on the LapSim simulator) are relevant to teaching laparoscopic colorectal surgery. To accomplish this task, 19 international experts rated all the LapSim tasks on a Likert scale (1–5) with respect to the degree to which they thought that a particular task should be included in a final technical skills curriculum. Results of the survey were sent back to participants until consensus (Cronbach's α >0.8) was reached. A cross-sectional design was utilized to define the benchmark scores for the identified tasks. Nine expert surgeons completed all identified tasks on the "easy," "medium," and "hard" settings of the simulator.*
Results. *In the first round of the survey, Cronbach's α was 0.715; after the second round, consensus was reached at 0.865. Consensus was reached for 7 basic tasks and 1 advanced suturing task. Median expert time and economy of movement scores were defined as benchmarks for all curricular tasks.*
Conclusion. *This study used Delphi consensus methodology to create a curriculum for an advanced laparoscopic procedure that is reflective of current clinical practice on an international level and conforms to current educational standards of proficiency-based training. (Surgery 2012;151:391-7.)*

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SURGERY RESIDENCY TRAINING PROGRAMS have traditionally used the operating room to teach surgical skills to trainees through graded responsibility under direct supervision. Because of the mandated decrease in resident work hours, ethical concerns regarding trainees learning procedures for the first time on patients, and the advent of new technology such as laparoscopy, this strategy is no longer feasible. As such, it has become necessary to shift a portion of residency training from the operating room to the surgical skills laboratory. Several recent systematic reviews have demonstrated that technical skills training in an ex vivo environment, whether on a bench-top model, or a virtual reality (VR) simulator, translates into an improvement in operating room performance.[1-4] Moreover, the technical improvements seen on a VR simulator have shown to persist for ≥10 cases in the operating room.[5] VR simulators have several advantages over bench-top simulators, including their ability to simulate complications, such as bleeding, their ability to automatically generate assessment parameters allowing for comparison between individuals and performances, as well as the fact that they are able to simulate tasks at varying levels of difficulty allowing for a natural gradation of training.[6]

With the strong body of evidence supporting the role of VR simulation in technical skills training, it is somewhat surprising that outside of the realm of research studies, few curricula based on training using VR simulation have been developed for minimally invasive procedures. Several groups

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have described curricula for basic laparoscopy, including curricula for basic minimally invasive tasks, or for less complex procedures such as laparoscopic cholecystectomy.[7-9] Although these curricula represent an important step in defining VR curricula for minimally invasive procedures, and largely conform to current educational theories regarding proficiency-based learning and distributed practice, as a group, they have been developed largely using local expertise. Specifically, experts at 1 institution determine which tasks or components are included in the final curriculum. To ensure the applicability of the developed curricula, it is essential that the final educational product be reflective of practice across diverse institutions. In addition, to our knowledge, no technical skills curricula using VR simulation have been described for advanced minimally invasive procedures.

Laparoscopic colorectal surgery is considered an advanced, minimally invasive procedure. Performing this procedure successfully involves ligating large blood vessels, working in multiple quadrants of the abdomen, and creating a viable anastomosis.[10] A long, variable learning curve[11] has been described for laparoscopic colorectal surgery, which underscores the necessity of developing a technical skills curriculum for learning this procedure, ideally in a simulated environment. The purpose of this study is 2-fold. Our first aim was to use consensus methodology to develop a technical skills curriculum based on VR for laparoscopic colorectal surgery. Our second aim was to define expert benchmarks of proficiency for this curriculum. We hypothesized that the Delphi method of consensus would be a feasible means of developing a technical skills curriculum for this advanced minimally invasive procedure that is reflective of international practice.

METHODS

Study design. This study used Delphi methodology to obtain consensus on the essential components of a VR curriculum for laparoscopic colorectal surgery. In addition, a cross-sectional design was utilized to determine expert levels of proficiency for the defined curriculum. The study was approved by the local institutional review board.

Participants for Delphi consensus. Participants for the Delphi consensus portion of the study were required to be leaders in their clinical field as evidenced by their role as opinion leaders within organizations such as The American Society of Colon and Rectal Surgeons, the Society of Gastrointestinal and Endoscopic Surgeons, or other national surgery societies. Furthermore, they were required to be familiar with the VR system used for the curriculum. Finally, the experts were required to be practicing surgeons who were involved in training laparoscopic colon and rectal surgery both at the resident and continuing professional development level. Twenty experts were recruited by e-mail to respond to an on-line survey. The experts were intentionally selected to represent a wide geographic area. In North America, 11 experts were contacted, and in Europe, 9 experts were contacted with the assistance of the Dutch Society for Endoscopic Surgery. Membership of the expert panel was not revealed to the survey participants.

On-line survey. The VR system that was utilized for the technical skills training portion of the curriculum was the LapSim laparoscopy trainer (Surgical Science, Gothenburg, Sweden). Construct validity, learning curves, and transfer of skills learned on the LapSim have been demonstrated.[5,12-17] The system consists of 11 basic tasks, 10 advanced tasks, and 6 procedural tasks specific to general surgery. Not all tasks on the LapSim, however, are relevant to laparoscopic colorectal surgery. The role of the Delphi panel was to determine through expert consensus those tasks that are relevant to teaching the technical skills required to perform laparoscopic colorectal surgery. These tasks were compiled into an on-line survey using via Survey Monkey (Palo Alto, CA). The participants in the expert panel were required to rate each identified task on a Likert scale from 1 to 5 detailing the degree to which they agreed or disagreed that a particular component should be included in a final technical skills curriculum. Results of the survey were sent back to participants with group averages and standard deviations until expert consensus was reached. Expert consensus was pre-defined as Cronbach's α >0.8, which has been shown to be an acceptable method of consensus determination.[18]

Final structure of the technical skills curriculum. After Cronbach's α >0.8 was achieved for the on-line survey, an outline of the final technical skills portion of the curriculum was created. Specific curricular tasks that over 80% of the experts rated as either 4 (agree) or 5 (strongly agree) on the final scale were included in the final technical skills curriculum. The technical portion of the final curriculum will require execution of the identified tasks on the "easy," "medium," and "hard" levels of the simulator. The settings for each level were taken from a recent European study in which consensus was reached on defining levels for the LapSim Basic Skills 3.0 package.[19] Levels for the tasks that were not discussed in the European consensus document (handling intestines, and stitch and square knot) were defined using an identical concept with local expertise.

Participants for expert benchmark levels. Nine experts in minimally invasive surgery were identified. An expert was defined as an individual who has completed >100 advanced minimally invasive procedures.

Tasks. Each expert was familiarized to the simulator by a member of the study team (VP or MG). Experts watched the instructional video for each task but did not warm up or practice on the simulator. During the familiarization period, the expert had opportunities to ask questions. Each expert completed each component of the curriculum on the "easy," "medium," and "hard" levels in a predefined sequence. No assistance was provided during completion of the curriculum.

Generation of expert benchmark scores. Experts were scored based on the automatic assessment parameters generated by the simulator. The parameters of interest were time, as well as those parameters related to economy of motion, specifically instrument angular path and path length. Expert benchmark scores for "time," "path length," and "angular path" were determined for each curricular component on the 3 levels (easy, medium, and hard) by calculating the median score of the 10 experts.

Statistical analysis. For the second round of the consensus survey, mean values and standard deviations were calculated for all LapSim tasks and were reported back to the expert panelists. Cronbach's α was used to determine consensus on the final curriculum tasks among the expert panelists. Median expert scores were calculated in order to determine expert levels of proficiency for the identified curricular tasks. All statistical analysis was performed on SPSS (Statistical Package for Social Sciences version 18.0, Chicago, IL).

RESULTS

Of the 20 experts contacted to participate in the Delphi panel, 19 responded to the first round of the consensus survey. The responses of 2 respondents were excluded from analysis, the first because the respondent completed less than one third of the survey, and the second because the respondent gave each curricular task the same score, indicating an apparent lack of attention to the survey process. After the first round of the survey, Cronbach's α was 0.715, indicating a lack of consensus. Twelve experts completed the second round of the survey. After the second round, consensus was achieved with a Cronbach's α of 0.865. After consensus was reached, the LapSim tasks that 80% of the panel rated as a 4 or 5 on the Likert scale were included in the final curriculum (Table I). Easy, medium, and hard levels were defined for each curricular task (levels available on request). Nine experts completed the VR curriculum in its entirety. Median expert scores were set as benchmarks for each task on each of the 3 levels of difficulty (Table II).

DISCUSSION

This study used the concept of a Delphi consensus methodology to develop a curriculum for an advanced laparoscopic procedure that is reflective of current clinical practice on an international level and conforms to current educational standards of proficiency-based training. The main purpose of our study was to design a procedural skills curriculum that results in improved technical proficiency when performing laparoscopic colorectal surgery in the operating room. Very few VR curricula have been developed for minimally invasive procedures.[7-9] Moreover, these curricula have been developed based on local expertise. The design of a VR curriculum for laparoscopic colorectal surgery in this study represents a departure from these traditional methods of curricula development. The Delphi methodology was used such that the final curriculum represents consensus among international experts regarding which component psychomotor tasks are essential to decrease the learning curve associated with this procedure. This approach is particularly important because many of the LapSim tasks show construct validity,[12,19-22] but are not necessarily relevant for learning laparoscopic colorectal surgery.

The advantages of the Delphi method have been well described in the literature.[18] Although the Delphi methodology has been successfully utilized in the development of diagnostic criteria, clinical scales, research questions, and evaluation tools for technical skills,[18,23-25] to our knowledge this is the first time that it has been used in the development of a technical skills curriculum. The identified tasks represent the consensus of experts in North America and Europe. Currently, there is no consensus in the literature regarding the number of experts required for a robust expert panel in the Delphi consensus process.[26,27] We elected to contact 20 experts with an expected response of 15 because we were hoping to balance a wide variety of expert opinion with selecting individuals

Table I. LapSim tasks included in the final virtual reality (VR) curriculum

LapSim task	Percentage of experts endorsing the task in the final curriculum	Task included in the final VR curriculum
Camera navigation	66	No
Instrument navigation	58	No
Coordination	83	Yes
Grasping	83	Yes
Cutting	100	Yes
Clip applying	92	Yes
Lifting and grasping	92	Yes
Suturing	58	No
Precision and speed	25	No
Handling intestines	100	Yes
Fine dissection	92	Yes
Cholecystectomy part 1	17	No
Cholecystectomy part 2	8	No
Needle passing	50	No
Interrupted stitching	76	No
Running stitching	83	No
Square knot	76	No
Surgeon's knot	67	No
Stitch and square knot	83	Yes
Stitch and surgeon's knot	83	No
Interrupted suturing	92	No
Running suturing	92	No
Side-to-side anastomosis	76	No
Appendectomy loop technique	33	No
Appendectomy single staple task	67	No
Appendectomy dual staple task	33	No
Appendectomy optional staple task	50	No
Peg transfer	33	No
Pattern cutting	42	No
Endoloop	58	No

who were thought to be invested in the process. During the survey process, the number of expert respondents decreased by 29%, from 17 in the first round, to 12 in the second round. This decrease in respondents is relatively consistent with what has been described in the literature.[18,28,29] Because the expert panelists were chosen among a fairly homogeneous group with respect to qualifications, it was thought that this dropout rate would not alter the final result of the panel. Although the dropout of respondents in the panel of experts of often expected with the Delphi process, using Cronbach's α to determine consensus helps to mitigate this phenomenon, because analysis using Cronbach's α is sensitive to the number of panelists, and a decrease in panelists is reflected by a corresponding decrease in α. The increase in Cronbach's α on the second round of the survey suggests that the increase in consensus more than offset the loss of panel members.

Based on the results from the Delphi process, 7 basic tasks and 5 suturing tasks were rated by >80% of the experts as either a 4 or 5 on the Likert scale. After review of the tasks selected, we elected to choose the stitch and square knot task as a representative suturing task, because it was felt that including 5 suturing tasks was redundant and would potentially be a source of frustration for the trainees. Although suturing in a VR environment has transfer validity, trainees at a more junior level can have difficulty learning suturing on a VR system and report low levels of face validity for this particular task.[30-32]

Creating expert benchmark levels of proficiency is essential in the development of a proficiency-based curriculum.[33] Several studies have demonstrated that learning curves on VR simulators vary between individuals at the same level of training.[34,35] All experts completed this phase of the study. The variability of the experts' scores is reflected in the relatively large interquartile ranges for each benchmark level of proficiency (Table II). This variability can be explained by the fact that although the experts had all completed >100

Table II. Expert levels of proficiency for the curricular tasks

Level	*Time (s)*	*Right instrument path length (m)*	*Right instrument angular path (°)*	*Left instrument path length (m)*	*Left instrument angular path (°)*
Coordination					
1	59 (47–76)	1.79 (1.49–2.45)	492 (392–729)	0.66 (0.18–0.87)	178 (73–283)
2	55 (41–66)	1.52 (1.44–1.73)	419 (368–455)	0.51 (0.36–0.79)	134 (109–225)
3	67 (56–86)	1.89 (1.61–2.15)	478 (418–540)	0.73 (0.64–1.46)	274 (219–478)
Grasping					
1	Right instrument time: 40 (35–49)	1.654 (1.45–2.12)	337 (277–529)	—	—
	Left instrument time: 41 (34–51)	—	—	1.55 (1.35–2.15)	380 (297–395)
2	Right instrument time: 51 (41–86)	1.98 (1.82–2.63)	354 (326–432)	—	—
	Left instrument time: 67 (55–82)	—	—	2.25 (1.64–2.96)	408 (348–583)
3	Right instrument time: 61 (54–86)	2.46 (2.20–2.79)	423 (403–480)	—	—
	Left instrument time: 90 (55–96)	—	—	2.45 (2.02–3.11)	443 (361–556)
Cutting					
1	92 (75–108)	1.17 (0.96–1.46)	239 (203–352)	0.93 (0.86–1.35)	234 (195–313)
2	70 (51–84)	0.87 (0.70–1.06)	180 (141–226)	0.57 (0.50–0.71)	157 (122–175)
3	88 (67–154)	1.03 (0.75–1.43)	190 (143–305)	0.85 (0.62–1.30)	212 (127–285)
Clip applying					
1	104 (80–134)	1.27 (1.13–1.70)	174 (164–242)	1.41 (1.11–1.70)	223 (177–286)
2	111 (60–165)	1.46 (0.84–3.25)	268 (106–470)	1.41 (0.69–2.25)	217 (94–345)
3	109 (84–143)	1.27 (1.16–2.30)	196 (125–461)	1.44 (0.83–1.65)	249 (116–282)
Lifting and grasping					
1	103 (90–115)	1.98 (1.60–2.28)	420 (346–490)	2.12 (1.65–2.23)	445 (353–498)
2	98 (83–112)	1.95 (1.69–2.28)	402 (343–480)	1.93 (1.80–2.39)	431 (377–461)
3	122 (99–139)	1.91 (1.73–2.43)	429 (382–527)	2.06 (1.80–2.41)	428 (404–505)
Handling intestines					
1	88 (66–101)	2.01 (1.64–2.24)	527 (440–601)	2.64 (1.78–3.89)	712 (482–989)
2	101 (74–113)	2.81 (2.05–4.65)	741 (552–1,161)	3.34 (2.58–5.00)	921 (642–1,223)
3	137 (111–179)	5.32 (3.60–5.58)	1,361 (927–1,548)	6.19 (4.38–7.42)	1,549 (1,199–1,702)
Fine dissection					
1	72 (67–79)	0.56 (0.53–0.64)	117 (111–124)	0.37 (0.31–0.46)	82 (70–104)
2	91 (73–125)	0.69 (0.50–0.93)	116 (99–176)	0.33 (0.26–0.41)	74 (51–96)
3	85 (67–117)	0.63 (0.52–0.77)	112 (104–115)	0.28 (0.27–0.41)	63 (57–88)
Stitch and square knot					
N/A	329 (287–371)	5.41 (3.54–6.73)	1,323 (910–1,650)	5.79 (4.05–7.20)	1,277 (959–1,723)

Data are presented as median values (interquartile range).

minimally invasive procedures independently, they had variable levels of experience on the VR simulator, and this variability likely resulted in several outlying scores. Median scores, rather than mean scores, were used to minimize this outlier effect on the various benchmarks. In addition, it was somewhat surprising that the experts' median scores did not consistently decrease as they progressed through the 3 levels of difficulty for each task (Table II). In fact, a common pattern was for the expert score to increase from level 1 to 2 and then to decrease at level 3. This observation may be related to the fact that the change in difficulty from level 1 to 2 might not have been great enough to completely mitigate any familiarization and learning effects on the simulator, whereas the increase in difficulty from level 1 to 3 was substantial enough to produce a decrease in performance across most tasks and performance measures.

The LapSim VR simulator automatically computes performance metrics, such as time, economy of motion, and error parameters. Interestingly, construct validity seems to be limited to time and economy of motion scores rather than error scores.[12,19-22] Aggarwal et al[36] attribute this to the inherent difficulties in defining a surgical error. As such, in this study, the parameters of time and economy of motion rather than error scores were chosen to represent the expert benchmark levels of proficiency. In addition, because construct validity has been determined for the majority of the LapSim tasks, repeating a construct validity assessment was deemed unlikely to add additional value to this described study.

Although the use of the LapSim as the VR simulator for this curriculum can be criticized because unlike some other VR simulators, the LapSim does not contain procedural-based tasks specifically related to laparoscopic colorectal surgery, it should be emphasized that the role of this technical skills training curriculum is to teach the psychomotor component skills to perform an advanced laparoscopic procedure. Currently, there are no studies comparing the efficacy of VR task-based training with procedural based-training on technical proficiency in the operating room. Rather, the bulk of evidence seems to suggest that basic task training on VR simulators translates to improved performance on both the simulator as well as to nonanalogous tasks in the operating room. Moreover, it is important to emphasize that this technical skills curriculum, based on VR training, is designed to teach the psychomotor tasks necessary to perform laparoscopic colorectal surgery, not the cognitive elements related to performing the procedure, such as understanding the flow of the operation or troubleshooting. It is also important to note that the strength of the curriculum is contingent on the rigor of the Delphi process and the experts who contributed their opinion. Unfamiliarity regarding the subtleties of the specific VR tasks could lead the experts to potentially underrate or overrate exercises, thus introducing a level of bias into the VR curriculum. We attempted to minimize this potential source of bias by first being judicious in the expert panel selection and ensuring that panelists were familiar with the LapSim system, not simply VR simulation in a general sense. In addition, we chose the cutoff for task inclusion as >80% of the participants rating the task as either a 4 ("agree") or a 5 ("strongly agree") on a Likert scale to ensure that potential outlying opinions were not factored into the final consensus of the group.

This technical skills curriculum based on VR simulation, using the LapSim, is to our knowledge the first curriculum designed for an advanced minimally invasive procedure such as colorectal surgery. Moreover, although the design of the curriculum conforms to current educational theories regarding proficiency-based training, our approach represents a departure from the traditional curricula designed locally in the literature. The tasks contained within this curriculum were decided on based on international expert consensus determined using Delphi consensus methodology. This approach represents 1 means of developing a comprehensive technical skills curriculum for laparoscopic colorectal surgery. After acquiring the necessary psychomotor tasks on the VR component of the curriculum, we believe that trainees should also participate in cognitive training, as well as a training session in the cadaver laboratory designed to integrate their acquired motor and cognitive skills. We expect that residents trained using this method of systematic technical skills training will exhibit superior technical ability in the operating room compared with residents trained using conventional methods. This approach has the potential to affect not only technical skills acquisition, but also to improve patient care in the operating room. The use of this combined approach of technical skills training using VR simulation, cognitive training, and training in a cadaver laboratory requires further investigation and validation.

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