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Surgeon-authored Virtual Laparoscopic Adrenalectomy Module is Judged Effective and Preferred over Traditional Teaching Tools

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Abstract

Objective—The study assesses user acceptance and effectiveness of a surgeon-authored virtual reality training module authored by surgeons using the Toolkit for Illustration Procedures in Surgery (TIPS).

Methods—Laparoscopic adrenalectomy was selected to test the TIPS framework on an unusual and complex procedure. No commercial simulation module exists to teach this procedure. A specialist surgeon authored the module, including force-feedback interactive simulation and designed a quiz to test knowledge of the key procedural steps. Five practicing surgeons with 15 to 24 years of experience peer-reviewed and tested the module. Fourteen residents and nine fellows trained with the module and answered the quiz, pre-use and post-use. Participants received an overview during Surgical Grand Rounds session and a 20-minute one-on-one tutorial followed by a 30 minute of instruction in addition to a force-feedback interactive simulation session. Additionally, in answering questionnaires, the trainees reflected on their learning experience and their experience with the TIPS framework.

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Authors' Contributions

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Acquisition of data: Kurenov

Statistical Analysis and data interpretation: Attwood, Kurenov, Peters

Drafting of manuscript: Kurenov, Peters, Cendan

Software Programming: Dindar, Peters

Study supervision: Cance

Disclosures

Mr. Kurenov, Mr. Dindar, Ms. Nawotniak, Drs. Attwood, Cance, Cendan, Cherr, Hassett and Peters have no conflict of interest of financial ties to disclosure.

Results—Correct quiz response rates on procedural steps improved significantly post-use over pre-use. In the questionnaire, 96% of the respondents stated that the TIPS module prepares them well or very well for the adrenalectomy, and 87% indicated that the module successfully teaches the steps of the procedure. All subjects indicated that they preferred the module compare to training using purely physical props, one-on-one teaching, medical atlases, and video recordings.

Conclusions—Improved quiz scores and endorsement by the participants of the TIPS adrenalectomy module establish the viability of surgeons authoring virtual reality training.

Keywords

surgical simulation; education; training; laparoscopic adrenalectomy; haptic device

Introduction

With increased use of minimally invasive surgery (MIS), concerns for patient safety mounting and work hours restricted, training for MIS outside of the operating room is a necessity. Traditional resources, such as textbooks, videos, anatomical atlases, and computer animations, have been complemented by formalized and validated proficiency assessment on box or video trainers such as the Fundamentals of Laparoscopic Surgery.^{1,2} However, box-trainers only cover basic psychomotor drills, not the more complex safety and anatomic challenges encountered in a complete procedure.

Virtual reality (VR) trainers have been suggested to bridge this gap²⁻⁴ by allowing trainees to practice decision making and execution prior to entering the OR. Despite a multitude of simulators available⁵⁻¹², there remains a need for easily accessible, affordable and customizable training simulators. For example, the latest version of the Simbionix trainer⁶ provides twelve *basic, non-customizable* MIS procedures and costs approximately \$50,000. Moreover, as newer MIS procedures are being introduced, creating new training modules is neither cheap nor fast and with rare procedures likely to receive low priority for simulation production. To develop new VR training modules requires months, even years, of intricate back- and-forth discussion between engineers, computer scientists and medical experts. Even then, such training modules do not reflect specialized scenarios or allow a surgeon-educator to implement an individual variation in technique, which is an important component of the master-apprentice relationship in traditional surgical education.

Enabling surgeon-educators to create and customize training modules by themselves, especially for less common procedures, is the goal of the Toolkit for Illustrations of Procedures in Surgery (TIPS).^{13,14} TIPS is a nascent low-cost computer-based environment supporting expert surgeons in creating and sharing laparoscopic surgery training modules. The surgeon-author enters a list of tasks and safety issues that is used to initialize 3D anatomy and to generate an instructional sequence and quizzes. The modules include interactive force-feedback simulation of the critical steps in surgical procedures in a 3D virtual anatomic environment. Force feedback in these simulations is not intended to replace the dexterity training provided by physical box trainers but to aid the trainee in remembering and recreating sequences of maneuvers that involve tissue management.

A prototype version of the TIPS framework was developed. The setup is shown in Figure 1. The most expensive components of the physical setup are two haptic devices, most recently available at \$600 each. To test the feasibility and user acceptance of surgeon-authored VR training units generated in TIPS, we chose to demonstrate the laparoscopic adrenalectomy procedure, since it requires a complex sequence of maneuvers. Tumors of the adrenal gland are uncommon, but are associated with substantial morbidity and mortality. Most adrenal tumors require resection.¹⁵ One of the standard techniques for laparoscopic right adrenalectomy starts with direct exposure of the inferior vena cava (IVC). After transection of the adrenal vein, traction is applied to the cut end of the vessel while the adrenal gland is removed. This technique is effective, but early dissection of the adrenal vein risks injury to the renal vein or IVC. Moreover, any adrenalectomy requires careful localization of the adrenal gland within the surrounding fat: if a surgeon attempts to directly approach the adrenal gland at the initial stage of the operation, it is easy to accidentally dissect into the gland.^{15–18}

The laparoscopic removal of an adrenal gland, therefore calls for dissection, cutting, cauterizing, stapling and tissue removal, a complex sequence of maneuvers that TIPS aims to address through training. No commercial simulation module exists to teach this procedure, possibly because modeling adrenalectomy is anatomically and procedurally complex. The interactive proof-of concept adrenalectomy training unit created via TIPS features fatty tissue¹⁹ and virtual peritoneum.^{20,21} While ultimately VR units are to be generated from high-level descriptions without the need for a developer, the adrenalectomy module presented herein still required developer intervention.

Materials and Methods

Laparoscopic right adrenalectomy was chosen due to its complexity of steps and tasks as a proof- of-concept for surgeon-authored training modules. Four tasks were selected for simulation by the author in consultation with three other senior laparoscopic surgeons: peritoneal access; exposure of the adrenal vein; dissection and division of the adrenal vein; and mobilization and removal of the adrenal gland (see <https://www.cise.ufl.edu/research/SurfLab/TIPS/data.php>).

Creating the Adrenalectomy Module

A specialist in laparoscopic adrenalectomy authored the TIPS right adrenalectomy module of this study. In the task-and safety list cycle (Figure 2, block 1) the surgeon-author deconstructed adrenalectomy into its major steps, each with a sequence of tasks, and each task into an action (spread, dissect, move, cut, etc.). Each action specified relevant anatomy, instruments, safety concerns, comments, and instructions with the web-based interface providing a choice of instruments and anatomy models from a database. Additionally, the surgeon-author uploaded or linked media (images and video clips) (Figure 3), specified the elasticity of the main anatomical models and placed fatty tissue into the simulation environment (cf. Figure 1).

Once the task-safety list was completed, the author granted access to reviewers for comments, concerns and additions. Five practicing laparoscopic surgeons from different

institutions reviewed the task-safety list with the goal of conceptual saturation – once no new ideas or critical steps were addressed, programming the procedure began in earnest. After the input of the reviewers was incorporated, the author executed the TIPS script that uses the task-safety list to initialize a sequence of instructional web pages with templates of instructions, attached media, simulation data, templates for a quiz (to be delivered pre-and post-use), and a summary report.

In the customization and virtual surgery cycle (Figure 2, block 2), the instructions are reviewed, the author's master performance on-screen recorded and acceptable ranges of key surgical interactions (*e.g.* force applied to the vein) are measured and stored.

The trainees' instruction and quiz cycle (Figure 2, block 3) is the focus of this study.

The final cycle, Kirkpatrick level 3 evaluation in the OR (Figure 2, block 4), is not part of this study.

The completed adrenalectomy module has five steps: (i) Patient positioning and preoperative considerations; (ii) Peritoneal access; (iii) Exposure of the adrenal vein; (iv) Dissection and division of the adrenal vein; and, (v) Mobilization and removal of the adrenal gland. All but the first steps are simulated in a force-feedback scenario. Every step was explained by accompanying "Important Concepts and Instructions", recorded video footage of the real surgery, and video of the same step in TIPS executed by the surgeon-author. The assembled module with its step by step instructions and TIPS simulation was installed on the test workstation, equipped with two haptic devices from Geomagic 3D Systems²² as shown in Fig. 1.

Study Participants

Given the experimental status of surgeon-authored VR training and the limited number of available residents and fellows, we enrolled all fourteen general surgery senior residents (medical doctors completing an additional five to seven years of specialization) and nine surgical oncology fellows (surgeons opting for sub-specialization) from two institutions, the Department of Surgery at the University at Buffalo, and the Department of Surgical Oncology at Roswell Park Cancer Institute (RPCI) to engage with the TIPS adrenalectomy module. In addition, five practicing general surgeons from three institutions (U Florida, U Buffalo, RPCI) with 15 to 24 years of experience tested and evaluated the module. To establish the participants' prior knowledge and experience, both with adrenalectomy and with surgical simulation, all participants were surveyed before engaging with the module.

The study, performed in the Department of Surgical Oncology at RPCI, Buffalo, NY, was exempt from Institutional Review Board (I-176010). At the outset, participants were classified as novices (fellows and residents) or experts (surgeons with 15 to 24 years of practicing experience).^{23,24}

Study Structure

The study of the adrenalectomy module consisted of four parts. In part A, all participants received a 20-minute introductory tutorial session with one-on-one mentoring to familiarize

them with the TIPS environment. During this part, participants were given a general overview of how the module and operative illustrations are authored within TIPS. In part B, novices answered (a) a four-question TIPS pre-use questionnaire and (b) a six-question adrenalectomy quiz. The quiz had been created by one of the surgical experts and vetted by the other surgeons prior to deployment. In part C, all participants engaged with the TIPS adrenalectomy module within the virtual environment (Figure 1). In part D, following the session, novices took the adrenalectomy quiz again, and then answered the qualitative post-use questionnaire and the TIPS evaluation questionnaire. Experts only filled out the TIPS evaluation questionnaire.

Tasks Performed

While both novices and experts tested and evaluated the adrenalectomy module, the quizzes were delivered to the novices only (with the quiz questions reviewed by the experts). The quizzes focused on the four core steps of adrenalectomy (ii-v) of Section 2.2: incision of the peritoneum, exposure of the adrenal vein, dissection and division of the adrenal vein, and mobilization and removal of the adrenal gland. Quizzes and evaluations were accessed through a secure online survey instrument (SurveyMonkey, <https://www.surveymonkey.com/>) and the resulting data were kept private and confidential.

To collect the participants' impression of the usefulness of the adrenalectomy module, novices were asked to reflect on their learning experience by answering five questions immediately after taking the post-use quiz. Experts had already commented on the scope of the module during the peer review in the task-safety-list cycle (Figure 2, block 1) and on details in the customization cycle (Figure 2, block 2).

To obtain feedback on the acceptance and viability of the TIPS framework, all participants (residents, fellows and experienced surgeons) were asked to score evaluative statements on a nine-level Likert scale. Here nine levels, rather than the standard five were used since two reviewers were concerned with clustering responses at the mean.²⁵

Statistical Analysis

The percentage of correct answers reported for the quiz, pre- vs. post-use, were compared by a one-sided McNemar's test.²⁶ All analyses were conducted in the Statistical Analysis System SAS v9.4 (Cary, NC)²⁴ at a significance level of 0.10, as this was a proof of concept study.

In this pilot study a type 1 error (false positive) is not detrimental, so that a less conservative significance level is appropriate. The raw data of Table 2 show that post training responses improve when there is room for improvement, and, the data of Table 3 show that the module is well received.

Results

The answers to the prior experience questionnaire (Table 1) showed that roughly half the novices (13 of 23) had prior exposure to adrenalectomy, but only one felt comfortable, whereas 10 were completely new to the procedure. The majority of the participants were

familiar with box trainers (19 vs. 4) but less than half (10 vs. 13) were familiar with any form of VR training. To brush up on rare procedures, the novices had been using in descending order of preference: textbooks, videos of surgeries, online archives and journal articles.

Knowledge Transfer (Quiz)

To assess the retention of key concepts after engaging with the module, the correct answers to the module-specific quiz developed by the author and reviewed by the experts were compared before and after using the module.

Table 2 lists the questions and responses in detail. All respondents provided correct answers in the post-use quiz on questions 2–5. The improvement is statistically significant for questions 3 and 5, the questions with the most procedural content; the answers to questions 2 and 4, which rely more on anatomic knowledge, were already largely correct in the pre-quiz. Question 1 also showed significant improvement with almost 80% of the respondents answering correctly as opposed to 25% before taking the module. Only question 6, was not answered satisfactorily by a majority of the respondents, although the correct response rate to this question more than doubled after respondents completed the module. These incorrect responses point to a lack of emphasis on the topic in the module and provide valuable feedback to the author.

Trainees' Assessment (Questionnaires)

While the expert feedback in the task-safety-list cycle (see Figure 2, blocks 1 and 2) commented on the face validity of the module, Tables 3 and 4 report on the 23 residents' and fellows' evaluation of their learning experience and their overall impression of the TIPS environment. Despite providing only a virtual experience, Table 3 shows that 87% of the respondents judged the module as preparing them well or very well for performing adrenalectomy, 100% agreed that the steps were illustrated well or very well and 78% stated that they came away with a good or very good understanding of the safety-critical point of the force needed to safely explore the anatomy. Although the emphasis of the module was on a fixed procedure, participants still thought that the module helps prepare for unforeseen operative complications.

The nine-level Likert responses summarized in Table 4 show that the interface with the robotic arms was judged natural and the key points of procedure were properly conveyed despite the lack of fulcrum (a simple hardware setup exists but makes mobile deployment more cumbersome). Notably, four of the five practicing expert surgeons thought that the module conveyed the key points of the procedure very well. The combination of haptic feedback, 3D interactive visual presentation and video examples was considered very positive, with the haptic feedback deemed most important. The respondents rated the module clearly better at illustrating adrenalectomy than physical models, one-on-one teaching, medical atlases, video, or even writing a detailed report using the literature.

Discussion

This paper reports a pilot study of user acceptance and effectiveness of a *surgeon-authored* virtual reality training module for minimally invasive adrenalectomy. Our main focus in testing the complex adrenalectomy module was technical feasibility: is the technology underlying surgeon-authoring TIPS framework sufficiently robust and realistic to elicit positive responses from specialists and trainees? No commercial simulation module exists to teach this complex procedure. A number of validations exist for commercial and academic simulators.^{27–35} The utility of several educational components leveraged by TIPS has been validated by multiple studies, including randomized controlled trials of multimedia content (video clips in CD-ROM or DVD of excellent surgical practice), online surgical e-web education and haptic-enabled virtual reality simulations. The studies point to improved competency in residents exposed to the techniques.^{36–40} However, none of these studies addresses the key aspect of TIPS, that content is controlled by the surgeon-author. Enabling surgeons to author force-feedback VR simulations is unexplored territory. Our study incorporated face validation by senior surgeons as well as solicitation of trainee feedback and knowledge assessment.

Enlisting 23 junior surgeons, the study used a sample size suitable for an exploratory evaluation of the concept.⁴¹ At the same time separating the participants into two cohorts with one having the full and the others having a partial learning experience was rejected due to a small number of participants. While our present study size was too small to draw conclusions for the general junior laparoscopic surgeon populations, the study did, however, demonstrate that surgeon-authoring in TIPS can be used to generate compelling teaching and training modules, even of a complex procedure. We have shown that the adrenalectomy module is perceived as useful for surgical education and medical training and that it effectively teaches knowledge about some key procedural steps of adrenalectomy. The knowledge retention was significantly improved on the quiz questions focusing on procedural steps. The improvement on questions relying primarily on anatomical knowledge was less significant only because of the already high rate of correct answers before engaging with the module. Responses to question 6, which was about freeing the adrenal gland, showed significant improvement but still an unsatisfactory rate of correctness. This outcome does not take away from the conclusion that procedural knowledge improves with taking the module, but illustrates the built-in feedback to the author-educator, suggesting increasing the emphasis on this aspect of the procedure.

Interestingly, the survey questionnaires showed that the interface via the robotic arms was perceived as natural and that the key points of procedure were properly conveyed - despite the lack of fulcrum in the tested setup. A simple hardware setup exists to provide a fulcrum, but adding the gantry makes deployment more cumbersome. Easy deployment of the training environment to places other than simulation centers is relevant since all but one participant thought the module useful to refresh their knowledge of the procedure.

Surprisingly, participants preferred TIPS instruction even over one-on-one instruction. Informal feedback pointed to the fact that participants appreciated the learner control of the

educational experience that is built into this personalized VR training. Nevertheless, debriefing by experienced surgeons remains a critical component of learning.⁴²

An inherent limitation of our study comes with choosing a technically complex and uncommon procedure to challenge the TIPS framework: laparoscopic adrenalectomy is not part of the techniques required in general surgery residency programs.⁴³ This precluded evaluating the adrenalectomy module's impact on decision-making in the OR with the same group of PGY-5 residents, and limited the study to theoretical knowledge of key steps of adrenalectomy. The impact of training with the modules on performance in the OR will be assessed for simpler, more common procedures, such as cholecystectomy or appendectomy using Kirkpatrick Level 3 studies (see Figure 2, block 4). We can also create appendectomy and Whipple procedure modules, requested by practicing GI surgeons. These modules and variants of laparoscopic appendectomy modules are expected to be ready for use soon.

The new TIPS modules will leverage the Simulation Open Framework Architecture (SOFA) from Inria to take advantage and contribute to the growing open source support for medical simulation.⁴⁴

Conclusions

This is a first evaluation of a surgeon-authored laparoscopic training module using TIPS. The interactive VR adrenalectomy module was created to test the framework's ability to teach an uncommon and complex procedure including tearing, cutting, cauterizing, stapling and removal of tissue. No commercial simulation module exists to teach this procedure. The study documented that a module designed for such a procedure within the TIPS framework was deemed effective by the vast majority of a cohort of 23 residents and fellows at two institutions, as well as by five experienced surgeons.

Currently, the module is used to enhance residency training. The next level of study of TIPS modules will focus on the translation of skills from the virtual environment to the operating room (Figure 2, block 4). These extensions will undergo further, content validity studies to establish their objective value and the impact of enabling surgeon-educators to author or customize force-feedback VR simulations.

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Figure 1.
Computer simulated TIPS environment: left - adrenalectomy simulation; right - instructions, questionnaires, and video. Two 6 degrees-of-freedom haptic devices provide physical feedback.

Figure 2.

Creation and validation cycle of TIPS training modules.

(1) Task and Safety List cycle. (2) Customization and virtual surgery cycle. (3) Trainee instructions and quiz cycle (=the focus of this study). (4) Kirkpatrick level 3 evaluation in OR (not part of this study).

[STEP 3 : Dissection and Division of Adrenal Vein]

PREVIOUS
NEXT

Important Concepts

Secure the vein in preparation for transection.
 Certification criteria:
 1. Use three clips: two on IVC side and one on gland side.
 (Precise position is critical as is confirmation that the clips are individually well placed and secure prior to cutting.)
 2. Switch instrument to shear and transect.

Instructions

- Watch the left video (real surgery).
- Watch the right video (TIPS simulation). Click arrow to play.
- Follow the steps properly, meeting the certification criteria.

Select the tools shown on this page before you begin the procedure.

Video of surgery

Video of TIPS

Tools Used

LEFT

Grasper

RIGHT

Clip applier

Shears

Figure 3.

Adrenalectomy module, Step 3, “Dissection and Division of Adrenal Vein”. Videos of real surgery and simulated example of surgery are juxtaposed. The trainee selects surgical instruments via the on-screen panel.

TABLE 1

Prior Experience questionnaire (23 residents & fellows)

	Question	Response					
		None	Participated in few	Did few (personally comfortable)	done many (expert)		
1	What is your prior experience with Laparoscopic Adrenalectomy?	10(44%)	12 (52%)	1 (4%)	0		
2	What methods do you use to prepare for infrequent/rare procedures? (Select All that apply)	Never prepare	Read a textbook	Select a journal articles from expert	Online web archives	Videos of surgeries	
		0	22 (96%)	9 (39%)	11 (48%)	15 (65%)	
3	What is your training level?	Non-medical	Medical student	Early trainee	Senior trainee	Faculty specialist	
		0	0	14 (61%)	9 (39%)		
4	Do you have prior experience with surgical simulators?	Box trainers (Yes/No)		High-fidelity, Virtual Reality (Yes/No)			
		19/4 (83%/17%)		10/13 (43%/57%)			

TABLE 2

Correct quiz answers (in **bold** in the table) pre-training (top) and post-training (bottom), residents & fellows. For example, question 1 had 26% correct answers before and 78% correct answers after working through the module.

	Question	Answer	From renal vein to diaphragm	From vena cava along the duodenum	Between the kidney and the inferior gland	P-value
1	When exposing the adrenal gland on the right, the peritoneum should be incised? (From renal vein to diaphragm)	Along superior gland 5 (22%)	6 (26%)	6 (26%)	6 (26%)	
2	When exposing the retroperitoneum which is the most critical organ that can be injured? (Vena cava)	Kidney 3 (13%)	18 (78%)	5 (22%)	0	<0.001
3	What can occur if you grasp the adrenal gland? (It can crack and bleed)	It's a good idea - can use it to retract 0	Vena cava 20 (87%) 23 (100%)	Diaphragm 0 0	Liver 0 0	0.125
4	When exposing the adrenal vein what tool is in your right hand? (Dissector)	Dissector 22 (96%) 23 (100%)	May cause elevation in blood pressure in patient with Cushing's 5 (22%) 0	16 (69%) 23 (100%)	It can crack and bleed	0.008
5	How many clips minimum should be used on the vena cava side? (2)	1 1 (4%) 0	Cauterizer 1 (4%) 0 2	3 3 (13%) 0	3	0.500
6	Which aspect of the adrenal gland should be freed first? (Inferior)	Medial 9 (39%) 10 (44%)	Lateral 19 (83%) 23 (100%)	Superior 5 (22%) 2 (9%)	Inferior 3 (13%) 7 (30%)	0.063

TABLE 3

Post-use assessment by trainee (23 residents & fellows)

Questions	Response				
	Very Poorly	Poorly	Adequately	Well	Very Well
1 Does the TIPS module prepare you for laparoscopic procedures?			3 (13%)	14 (61%)	6 (26%)
2 Can you visualize the steps of laparoscopic procedures?				7 (30%)	16 (70%)
3 Do you now understand the force needed to explore the anatomy?			5 (22%)	14 (61%)	4 (17%)
4 Does the TIPS module help prepare you to react to unforeseen operative complications?		1 (4%)	10 (43%)	9 (39%)	3 (13%)
5 If the kit is made available at your convenience, would you use it for refreshing knowledge?			1 (4%)	9 (39%)	13 (57%)

9 point Likert scale