Title: 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 created with 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 developed the module including force-feedback interactive simulation and 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 sessions and a 20-minute one-on-one tutorial before engaging in a 30 minute instruction plus force-feedback interactive simulation session. Additionally, in answering questionnaires, the trainees reflected on their learning experience and their experience with the TIPS framework. *Results.* Correct quiz response rates on procedural steps improved significantly ($p<0.10$) post-use over pre-use. In the questionnaire, 96% of the respondents stated that the TIPS module prepares 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 over 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 viability of surgeon-authored virtual reality training.

Keywords

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

1. 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-(video)-trainers such as the Fundamentals of Laparoscopic Surgery.[1] 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 fill the gap[2-4] by allowing trainees to practice decision making and execution prior to entering the OR. Despite a multitude of simulators available[5-9], there remains a need for effective, easily accessible and affordable training equipment. For example, a Simbionix trainer[5] providing five basic MIS procedures costs approximately $150,000. Moreover, as ever new MIS procedures are being introduced, creating new training modules is neither cheap nor fast. To develop new VR training modules requires months, even years, in an intricate back-and-forth 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 themselves, create and customize training modules, especially for less common procedures, is the goal of the Toolkit for Illustrations of Procedures in Surgery (TIPS).[10,11] TIPS is a nascent low-cost computer-based environment supporting expert surgeons in creating and sharing laparoscopic surgery training modules. The modules include interactive force-feedback simulation of the critical steps in surgical procedures in a 3D virtual

anatomic environment. The surgeon-author enters a list of tasks and safety issues that is used to initialize the 3D anatomy and serves as a scaffold for generating the instructional sequence and quizzes.

A prototype version of the TIPS framework was developed by the end of 2011. The setup is shown in Figure 1. The main cost of the physical setup are two haptic devices, most recently available at $600 each. The interactive simulation of the adrenalectomy module features fatty tissue[12] and virtual peritoneum.[13,14] This study reports on testing the TIPS adrenalectomy module over the years 2012 to 2014.

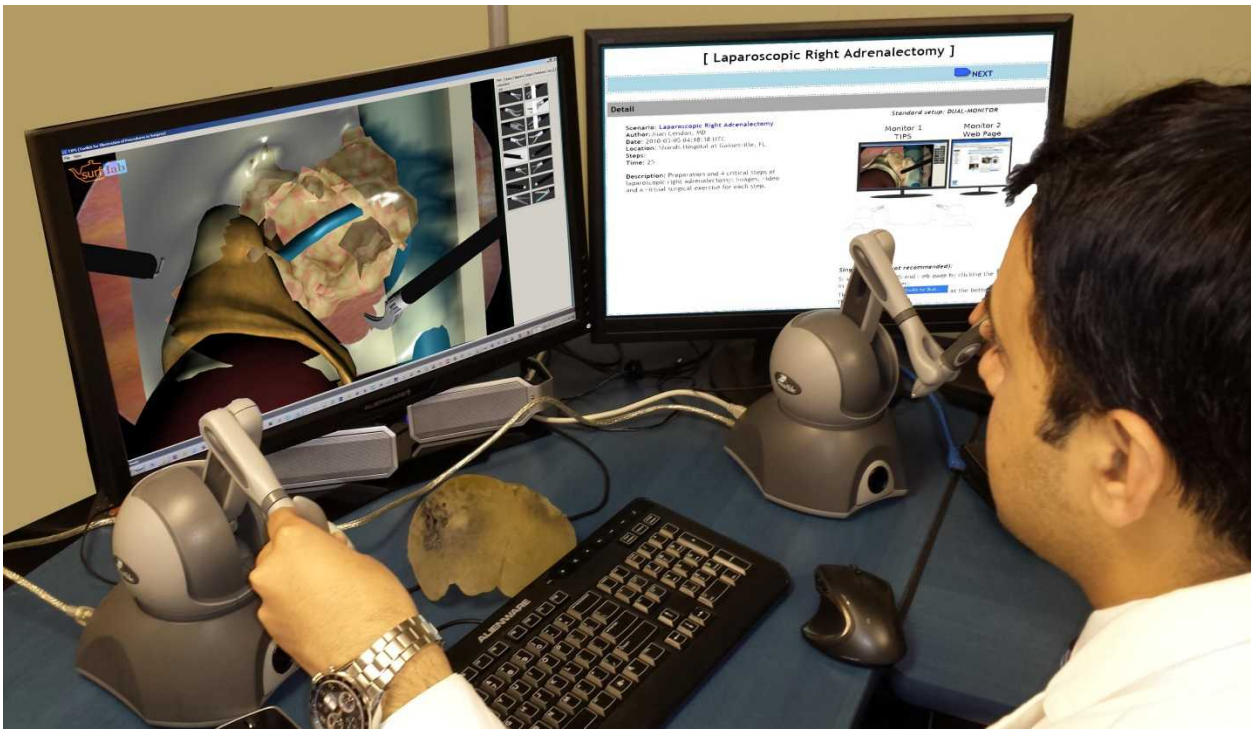

Figure 1. Computer simulated TIPS environment: left - adrenalectomy simulation; right - instructions, questionnaires, and video. Two 6 degrees-of-freedom haptic devices provide physical feedback.

2. Materials and Methods

2.1 Adrenalectomy Surgical Tasks

Tumors of the adrenal gland are uncommon but associated with substantial morbidity and mortality. For most adrenal tumors, resection is the only opportunity for cure.[15] The laparoscopic removal of an adrenal gland, calls for dissection, cutting, cauterizing, stapling and tissue removal. Adrenalectomy was chosen to challenge the TIPS framework with its anatomic complexity, procedural complexity and because of the low relative frequency of the procedure: no commercial simulation modules exist to teach this procedure.

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.[16,17]

2.2 Creating the Adrenalectomy Module

The TIPS right adrenalectomy module of this study was authored by a specialist in laparoscopic adrenalectomy. 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 specifies 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), specified the elasticity of the main

anatomical models and placed fatty tissue into the simulation environment (cf. Figure 1).

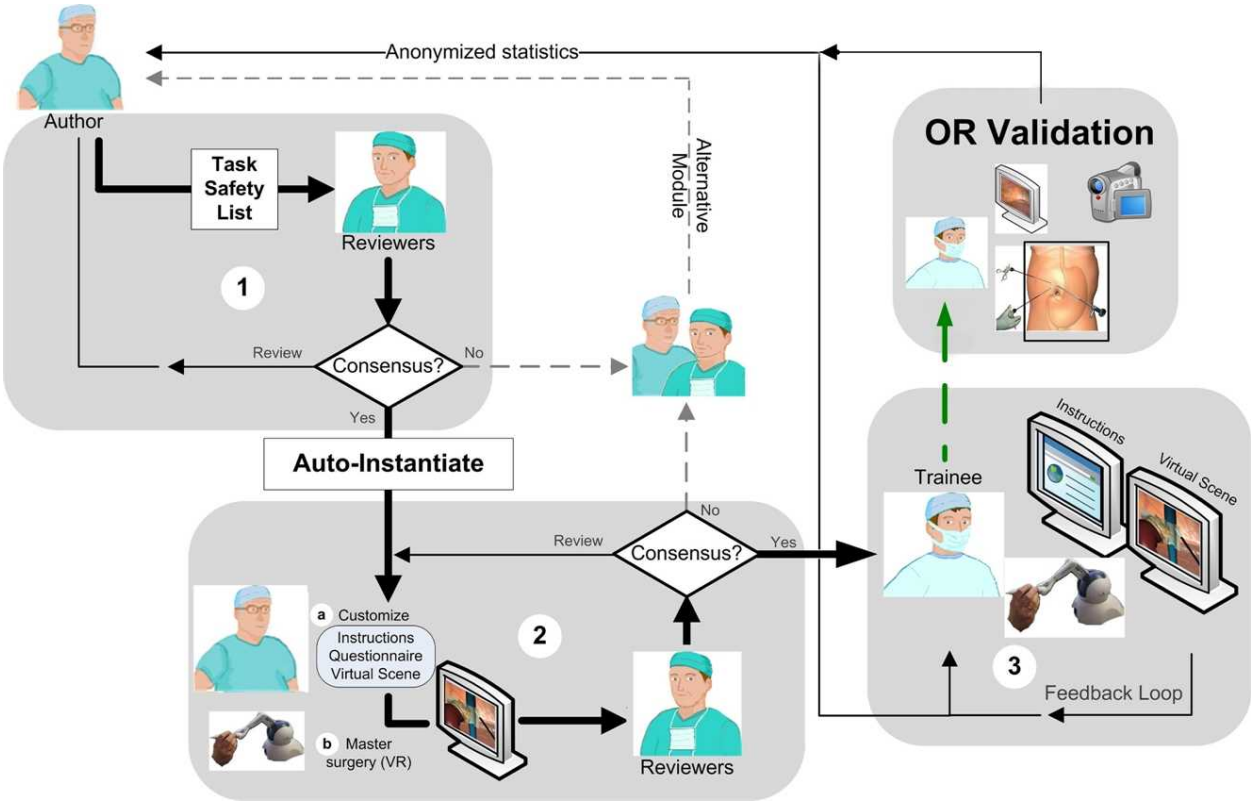

Figure 2. Creation and validation cycle of TIPS training modules.
(1) Task and Safety List cycle. (2) Customization and virtual surgery cycle. (3) Trainee instructions and quiz cycle (=*the focus of this study)*. (4) Kirkpatrick level 3 evaluation in OR (not part of this study).

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. 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. As a proof-of-concept, the adrenalectomy module instantiation required developer intervention.

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.

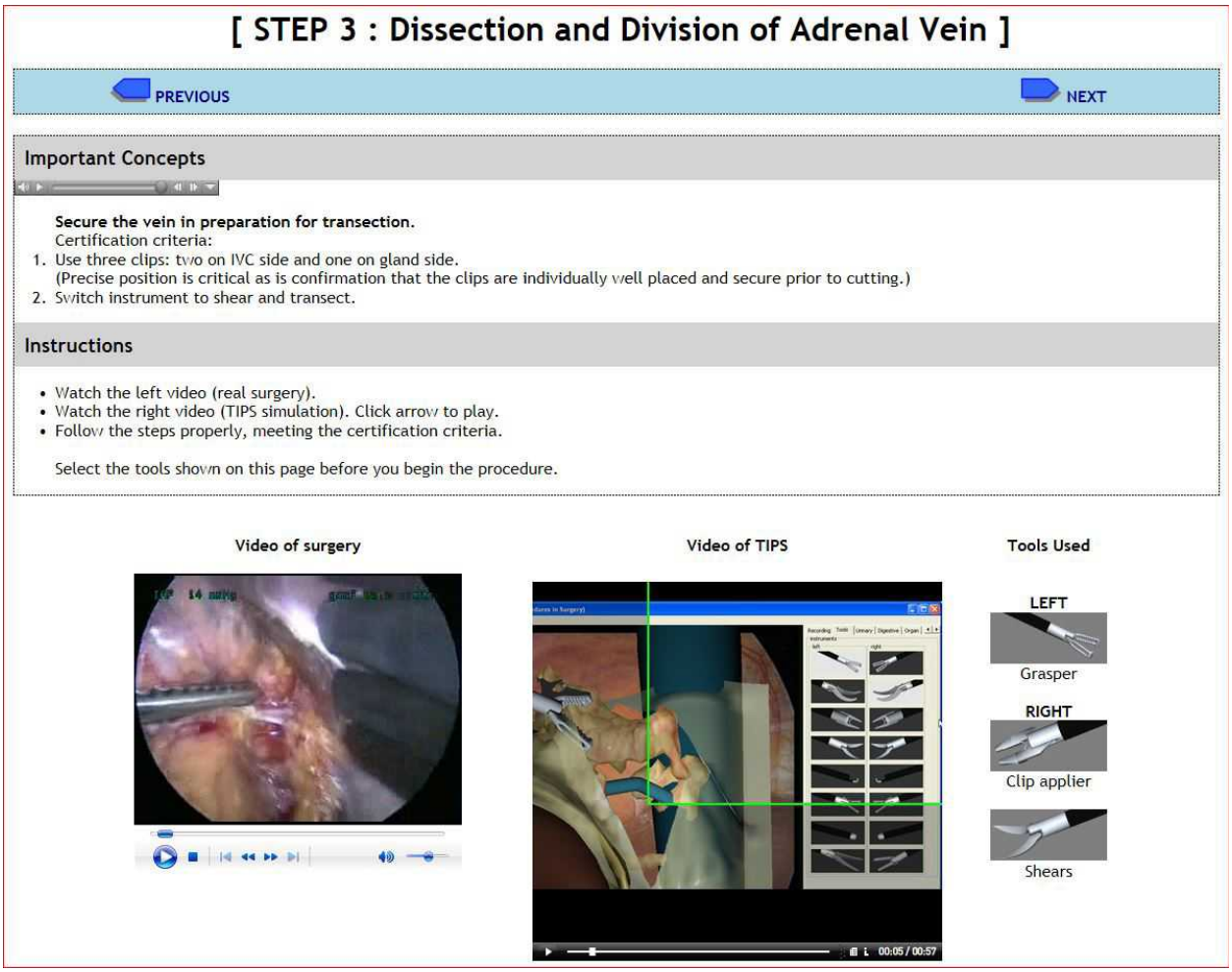

Figure 3. Adrenalectomy module, Step 3, "Dissection and Division of Adrenal Vein". Videos of real surgery and simulated example of surgery are juxtaposed. The trainee selects surgical instruments via the on-screen panel.

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; (v) Mobilization and removal of the adrenal gland. Every step is 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 Systems[18] as shown in Fig. 1.

2.3 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 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. 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).[20]

2.4 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) six-question adrenalectomy quiz. 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.

2.5 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 online 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 standard five were used since two reviewers were concerned with clustering responses at the mean.[21,22]

2.7 Statistical Analysis

The percentage of correct answers reported for the quiz, pre- vs. post-use, were compared by a one-sided McNemar's test.[23] All analyses were conducted in Statistical Analysis System SAS

v9.4 (Cary, NC)[24] at a significance level of 0.10, as this was a proof of concept study.

3. RESULTS

To establish the participants' prior knowledge and experience with adrenalectomy and surgical simulation, all participants were surveyed before engaging with the module. 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. Conversely, all but one participant were familiar with box trainers but less than half with 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.

3.1 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, relying more on anatomic knowledge, were already largely correct in the pre-quiz. Question 1 also shows significant improvement with almost 80% of the respondents obtaining the correct answer as opposed to 25% before taking the module. Only question 6, while more than doubling the correct response rate, was not answered satisfactorily by a majority of the respondents. This points to a lack of emphasis on the topic in the module and represents valuable feedback to the

author.

3.2 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 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 via 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.

4. DISCUSSION

Enabling surgeons to author force-feedback VR simulations is unexplored territory. The study went beyond face validity of an authored module by soliciting user feedback and testing retention of procedure-specific knowledge reinforced by engaging with the VR simulation. With 23 participants, the study used a sample size suitable for exploratory evaluation of the concept but short of size to allow extending conclusions to the general junior laparoscopic surgeon populations. The present study has, however, demonstrated that surgeon-authoring in TIPS can be used to generate compelling teaching and training modules, even of a complex procedure: that a resulting 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 low rate of correct answers to question 6 (freeing the adrenal gland) does not take away from that conclusion but illustrates the built-in feedback to the author-educator, suggesting to increase the emphasis on this aspect of the procedure.

Built into VR training is learner control of the educational experience. This played into the preference of participants for TIPS even over one-on-one instruction. While the study tested knowledge of key steps of adrenalectomy and collected perceptions of the users, future studies will evaluate Kirkpatrick Level 3 via. impact on decision making in the OR.

Demonstrating the adrenalectomy module triggered requests for inclusion of patient specific data and practicing GI surgeons were eager to see appendectomy and Whipple procedure modules. Variants of laparoscopic appendectomy are expected to be ready for use in the next rotation cycle of senior residents at RPCI.

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 a the vast majority of a cohort of 23 residents and fellows at two institutions, as well as by five experienced surgeons. Encouragingly, all but one participant thought the module useful to refresh their knowledge of the procedure.

Currently, the module is used as part of 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) to establish their objective value and the impact of enabling surgeon-educators to author or customize force-feedback VR simulations.

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AUTHORS' CONTRIBUTION

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Acquisition of data: Kurenov

Statistical Analysis and data interpretation: Attwood, Kurenov, Peters

Drafting of manuscript: Kurenov, Peters

Software Programming: Dindar, Peters

Critical revision of the manuscript for important intellectual content: Cendan, Cance

Study supervision: Cance

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TABLE 1. Prior Experience questionnaire (23 residents & fellows only)

	Question	Response				
1	What is your prior experience with Laparoscopic Adrenalectomy?	None	Participated in few	Did few (personally comfortable)	Done many (expert)	
		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	Read journal articles	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)**,** residents & fellows: (top numbers of each box) pre-use, (bottom numbers) post-use. For example, question 1 had 26% correct answers before and 78% correct answers after working through the module.

	Question	Answer				P-value
1	When exposing the adrenal gland on the right, the peritoneum should be incised?	Along superior gland	**From renal vein to diaphragm**	From vena cava along the duodenum	Between the kidney and the inferior gland	
		5 (22%) 0	6 **(26%)** 18 **(78%)**	6 (26%) 5 (22%)	6 (26%) 0	**<0.001**
2	When exposing the retroperitoneum which is the most critical organ that can be injured?	Kidney	**Vena cava**	Diaphragm	Liver	
		3 (13%) 0	20 **(87%)** 23 **(100%)**	0 0	0 0	**0.125**
3	What can occur if you grasp the adrenal gland?	It's a good idea - can use it to retract	May cause elevation in blood pressure in patient with Cushing's	**It can crack and bleed**		
		2 (9%) 0	5 (22%) 0	16 **(69%)** 23 **(100%)**		**0.008**
4	When exposing the adrenal vein what tool is in your right hand?	**Dissector**	Cauterizer			
		22 **(96%)** 23 **(100%)**	1 (4%) 0			**0.500**
5	How many clips minimum should be used on the vena cava side?	1	**2**	3		
		1 (4%) 0	19 **(83%)** 23 **(100%)**	3 (13%) 0		**0.063**
6	Which aspect of the adrenal gland should be freed first?	Medial	Lateral	Superior	**Inferior**	
		9 (39%) 10 (44%)	6 (26%) 4 (17%)	5 (22%) 2 (9%)	3 **(13%)** 7 **(30%)**	**0.063**

TABLE 3. Post-use assessment by trainees (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%)

TABLE 4. Evaluation of the TIPS environment (26 participants)

Question										
Is the interface natural or does it distracts from the task of adrenal vein isolation?		distract	-3	-2	-1	0	1	2	3	natural
							4 (15%)	**12(46%)**	**8 (31%)**	**2 (8%)**
Is the kit capable of conveying the key points of procedure: safe fatty tissue removal and lifting of the adrenal vein?		not at all	-3	-2	-1	0	1	2	3	very well
								9 (35%)	**12(46%)**	**5 (19%)**
Is the combination of media helpful in documenting the adrenalectomy?		not at all	-3	-2	-1	0	1	2	3	very helpful
	Haptic						**3 (12%)**	**13 50%)**	**7(26%)**	**3 (12%)**
	Visual 3D						**1 (4%)**	**12 46%)**	**9 (35%)**	**4 (15%)**
	Annotation: video, picture							**7 (27%)**	**13(50%)**	**6 (23%)**
Order the media in previous question by their usefulness in conveying the key safety issues when removing the adrenal gland, anatomy orientation (removal of fatty tissue), procedure sequencing (complete removal of fatty tissue before lifting the adrenal vein) and developing judgment about branching decisions (in the case of hemorrhage).	Order	1	2	3						
	Haptic	**9(35%)**	**12(46%)**	**5 (19%)**						
	Visual 3D	**8(31%)**	**15(57%)**	**3 (12%)**						
	Annotation: video, picture	**6(23%)**	**6 (23%)**	**14 54%)**						
		much worse	-3	-2	-1	0	1	2	3	much better
Is the kit better or worse for illustrating adrenalectomy than the media you have been exposed to before such as:	Physical models						**2 (8%)**	**13(50%)**	**10(38%)**	**1 (4%)**
	1 –on -1 teaching						**9 (35%)**	**9 (35%)**	**6 (23%)**	**2 (8%)**
	Medical atlases						**5 (19%)**	**3 (12%)**	**15(57%)**	**3 (12%)**
	CD, DVD-ROM						**1 (4%)**	**5 (19%)**	**17(65%)**	**3 (12%)**
Is authoring a procedure more or less effective than writing a detailed report on adrenalectomy?		less effective	-3	-2	-1	0	1	2	3	more effective
								2 (8%)	**7 (27%)**	**17(65%)**
Did you ever use a computer-based tool similar to this? If so, which one?		Yes*	No							
		7(27%)	**19(73%)**							

* Participants had a previous experience with Lap mentor™ from SIMBIONIX USA (Cleveland, OH), and other trainers