Surgical Endoscopy
https://doi.org/10.1007/s00464-025-12406-9

2025 SAGES POSTER

The virtual colorectal surgical trainer–ileal pouch-anal anastomosis simulator shows evidence of validity

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Received: 16 May 2025 / Accepted: 11 November 2025
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Abstract

Background Ileal pouch-anal anastomosis (IPAA) is a key procedure to master in colorectal surgery. It is one task of the Colorectal Objective Structured Assessment of Technical Skill (COSATS) of the American Board of Colon and Rectal Surgery. The virtual colorectal surgical trainer-IPAA (VCoST-IPAA) was designed as an innovative platform for training and assessing performance in this procedure. Our aim was to establish the validity of the simulator by demonstrating its ability to distinguish between levels of surgical expertise.

Methods In this IRB-approved study, general surgery residents and colorectal surgeons from our institution performed the IPAA procedure on the VCoST simulator. Nineteen task-specific metrics developed by expert consensus were included and automatically recorded by the simulator. Participants were divided into novice (PGY 1–2) and experienced (PGY 3–5 and faculty) groups. The Messick's unitary framework was used to assess the validity. The Mann–Whitney U test was used to compare the performance between the groups.

Results A total of 22 equally distributed participants were included in this study. The Mann–Whitney U test showed significant differences in performance between the two groups on the assessment of J-pouch length (3.67 for experienced vs. 1.50 for novices; $p = 0.01$) and the gap indicator during trocar retraction (3.89 vs. 1.50; $p = 0.04$). No significant differences in completion time (670.1 vs. 826.3 s; $W = 24$; $p = 0.09$) nor the total score computed using 18 metrics (76.33 vs. 70.50; $W = 65$; $p = 0.1$) were found.

Conclusions Our VCoST-IPAA simulator showed that J-pouch length and the gap indicator during trocar retraction were important predictors of performance between experienced and novice participants. Participants in our study performed an Altemeier procedure on our validated VCoST-rectal prolapse simulator before the IPAA procedure, which may have had a positive effect on the performance on the VCoST-IPAA simulator.

Keywords Colorectal surgery · Surgical simulation · Ileal pouch · Virtual reality simulation

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Ileal pouch-anal anastomosis (IPAA) is one of the most important and complex procedures in colorectal surgery, often reserved for patients requiring proctocolectomy due to conditions such as ulcerative colitis or familial adenomatous polyposis [1]. Due to its complexity and the level of skill required, IPAA is one of the procedures evaluated in the Colorectal Objective Structured Assessment of Technical Skill (COSATS) by the American Board of Colon and Rectal Surgery. Introduced in 2014, COSATS marked a crucial step as the first national technical skills examination incorporated into surgical board certification, with IPAA alongside other technically demanding open procedures such as coloanal anastomosis, handsewn bowel anastomosis, and rectal prolapse repair [2]. The steep learning curve of the IPAA is well documented, with evidence linking surgical proficiency to critical outcomes, including reduced leak rates and lower incidence of pouch failure [3, 4]. Worryingly, long-term anastomotic leak rates may reach as high as 15%, underscoring the urgency of competency-based training models to preserve patient outcomes [5]. While the stapled J-pouch technique is widely favored for its lower risk of stricture formation, improved functional outcomes, and reduced anastomotic tension [6], achieving mastery over each step—from proctocolectomy and mesenteric mobilization to pouch creation and anastomosis—remains challenging even for experienced surgeons [6–8].

Simulation-based training has shown strong potential for enhancing surgical skill acquisition in other domains, offering risk-free, reproducible environments for deliberate practice [9–11]. However, current options for IPAA simulation remain limited. Although cadaveric and animal models provide realistic anatomy and tactile feedback, they are costly, resource-intensive, and impractical for routine training [12]. Bio-tissue models, while more accessible, often fall short in replicating the procedural steps required for complex procedures [13]. This lack of IPAA-specific simulators presents a key barrier to standardized, objective, and proficiency-based training. Therefore, novel training tools are needed that combine anatomical realism, iterative practice, and objective evaluation in a cost-effective and scalable format.

To address this critical training gap, a novel virtual reality (VR) IPAA simulator was developed as part of a National Institutes of Health-funded initiative. The aim of our study was to establish the validity of the virtual colorectal surgical trainer-IPAA (VCoST-IPAA) simulator, supporting its potential role as a standardized training and assessment tool. By offering reproducible training scenarios with real-time objective performance metrics for assessment and feedback in a risk-free environment, this simulator may help accelerate proficiency in the IPAA procedure and advance competency-based surgical education.

Materials and methods

Study design

This study consisted of two main phases: (1) preliminary simulator preparation, including performance metrics development, and (2) assessment of validity, performed together with the VCoST-rectal prolapse (VCoST-RP), a simulator that was also developed and tested by this group. The present study specifically focuses on assessing the validity of the VCoST-IPAA simulator by evaluating surgical performance on a VR-simulated IPAA procedure. Messick's unitary framework was used to generate validity, specifically focused on the relationship to other variables domain [14, 15].

Development of performance metrics

A hierarchical task analysis was conducted for the IPAA to systematically deconstruct the procedure into tasks, subtasks, and motion-end effectors, a widely recognized approach in surgical skill assessment [16, 17]. This analysis was developed through expert consensus, supplemented by procedural insights from surgical textbooks and instructional workshop videos [18, 19]. The identification and refinement of primary tasks and subtasks were carried out under the guidance of an expert colorectal surgeon from this institution to ensure accuracy and clinical relevance.

Simulator development

The simulator for the IPAA procedure creates an immersive environment for surgical training through the combination of input/output devices, VR simulation, and performance metrics. The input/output devices include a VR headset and two 3D system haptic touch devices. A VR headset immerses users in the simulated environment while the haptic devices, which provide force feedback, allow users to interact with it. The simulation is self-contained and has everything needed for users to perform the procedure within the simulated operating room. There are tools such as a linear stapler with loads, a circular stapler, a needle driver, DeBakey forceps, and Allis clamps, all of which can be manipulated with haptic devices. These tools interact with objects in the environment such as a stapler and a simulated bowel to make the anastomosis. The simulator automatically records whether the participant successfully completed tasks based on performance metrics. A participant performing the IPAA procedure on the simulator is displayed in Fig. 1.

Procedure within the simulator

J-pouch creation initially consists of adjusting the desired size (length in cm) of the simulated bowel to create the J. An enterotomy is automatically created and the anastomosis between the two segments of the bowel is achieved through linear stapler insertion and firing. A new stapler load is required before the second insertion and firing further within the bowel. Then the anvil is placed inside the enterotomy, and a purse suture is made to secure it. Following this, using a circle stapler, the ileoanal anastomosis is performed. This phase consists of stapler insertion, trocar extension, attachment to the anvil, retraction, and firing. Once the stapler is removed, the donuts created can be examined. The last step consists of a leak check by inserting an insufflation device

Fig. 1 Participant performing the IPAA procedure on the VCoST-IPAA Simulator

into the rectal stump. The phases within the simulator are displayed in Fig. 2.

Once the procedure is complete, the performance metrics are automatically recorded and evaluated. These metrics ensure whether each step was done in the correct manner or not.

Study participants

This study was approved by our institutional review board (IRB #STU-2021–0202) and conducted at the Artificial Intelligence and Medical Simulation (AIMS) Lab at the University of Texas Southwestern Medical Center. General surgery residents and expert colorectal faculty surgeons were recruited to participate. Exclusion criteria included participants with difficulty in seeing objects in 3D even with adjustments of the intraocular distance in the head mount display in the immersive VR system (depth perception), and subjects prone to motion sickness or nausea when using the system.

For data analysis, subjects were distributed into either a novice group, including PGY-1 and PGY-2, or an experienced group, including PGY-3 to PGY-5 who have completed colorectal surgery rotations, simulated activities and are familiarized with both linear and circular staplers and faculty colorectal surgeons.

Experimental procedure

Prior to initiation, written informed consent was obtained from all subjects. Each participant completed an entry survey collecting demographic information and details of prior clinical and simulation-based training experience. Then, all subjects completed the rectal prolapse (Altemeier procedure) first before performing the IPAA on the VCoST simulator. While general instructions on simulator controls were provided, no task-specific guidance was given since performing the tasks within the simulated procedure was part of the assessment. They were given an hour to complete the procedure entirely. Upon completion, participants filled out an exit survey using a 5-point Likert scale to evaluate their perceptions of the simulator's utility and realism. Additionally, cognitive load during the simulation was assessed using the NASA Task Load Index (NASA-TLX) questionnaire.

Statistical analysis

Descriptive statistics were used to analyze performance scores for all participants as well as data from the entry and exit surveys. The normality of performance scores from the simulator and responses from both the NASA-TLX survey and the simulator survey was assessed using the Shapiro–Wilk test [20]. If the data followed a normal distribution, an independent *t*-test was conducted to compare differences between groups. For non-normally distributed data, a Mann–Whitney U test was applied. All statistical analyses were performed using R statistical software (version 4.4.0; R Core Team, 2022) [21].

Results

Hierarchical task analysis results

The hierarchical task tree analysis depicted in Fig. 3 was conducted to determine the tasks and subtasks of the IPAA procedure and the optimal sequence of execution. Three distinct main tasks were identified in the analysis: J-pouch

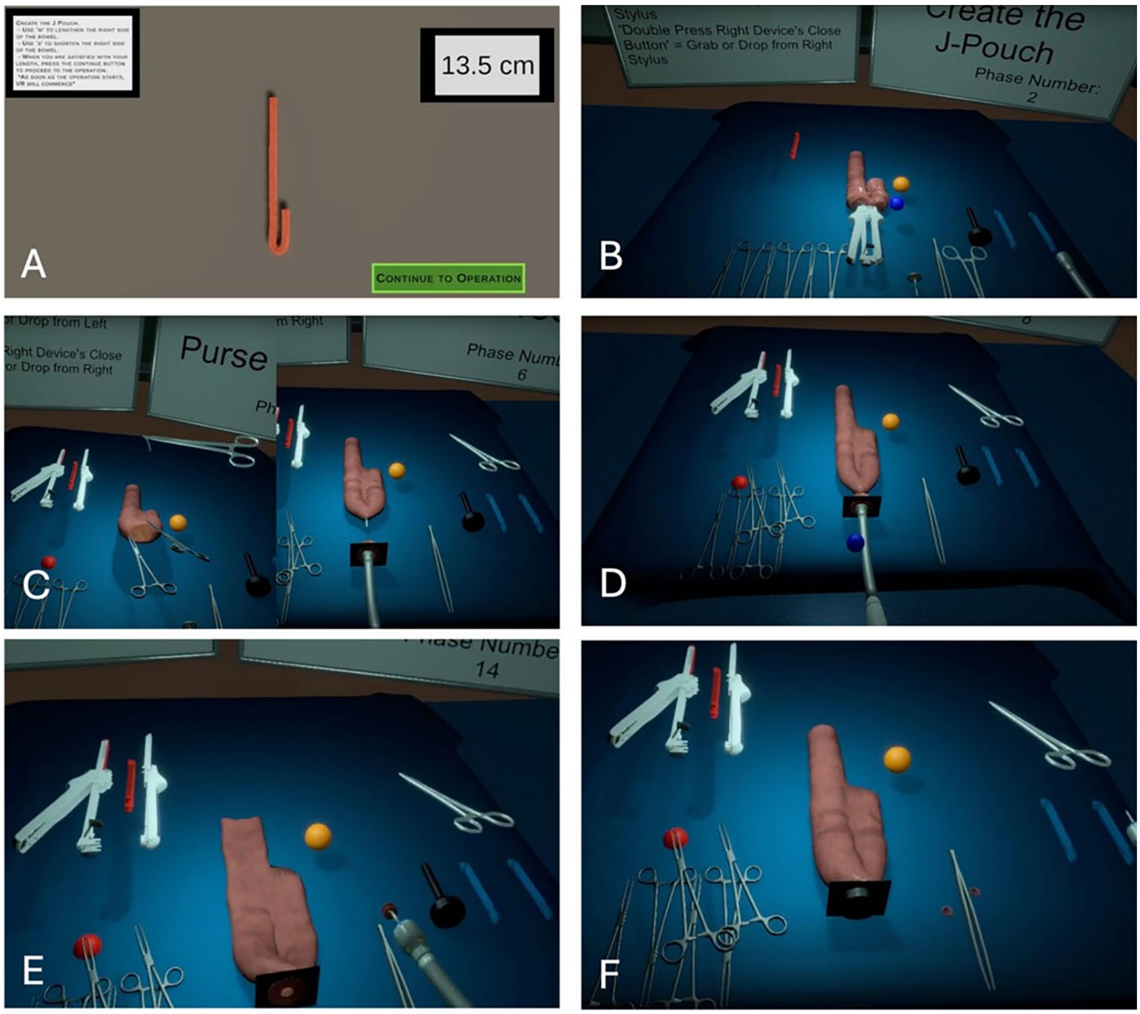

Fig. 2 Virtual reality ileal pouch-anal anastomosis simulator environment and phases: **A** bowel length size, **B** anastomosis with linear stapler, **C** purse suture and anvil securing, **D** ileoanal anastomosis with circular stapler, **E** donut examination, and **F** leak check

construction, ileoanal anastomosis, and post-stapler firing and leak evaluation. While "pouch tension" was included in the task analysis to represent a conceptual factor affecting anastomotic integrity, this metric was not quantitatively measured or recorded in the current version of the simulator. Details of all tasks and subtasks derived from this analysis are shown in Table 1. These task-specific metrics were automatically recorded by the simulator and were used to assess performance. Tool handling and suture handling were also considered for evaluation.

Demographics

A total of 22 subjects participated in this study. Eleven novices (PGY 1 to 2) and eleven experienced (PGY 3 to 5 who had completed colorectal rotation and faculty surgeons) were able to complete all phases of the study. Of those, 64% identified as male ($n = 14$) and 36% identified as female ($n = 8$).

Exit survey results

Descriptive statistics were computed for expert evaluations of various aspects of the simulation, including anatomical and model realism, interface design, force feedback, and overall resemblance to the real-life task. The average rating for "realism of the anatomy" was 3.55 ($SD = 1.13$), while "realism of models and textures" had a mean of 3.27 ($SD = 1.19$). A summary of the experienced group results for all the categories is displayed in Table 2.

After completion of the task, the perceived cognitive and physical workload was assessed with the 10-point NASA-TLX. In this case, data were normally distributed, so *t*-tests were calculated and showed no statistically significant difference in the means between experienced and novices. All results are summarized in Table 3.

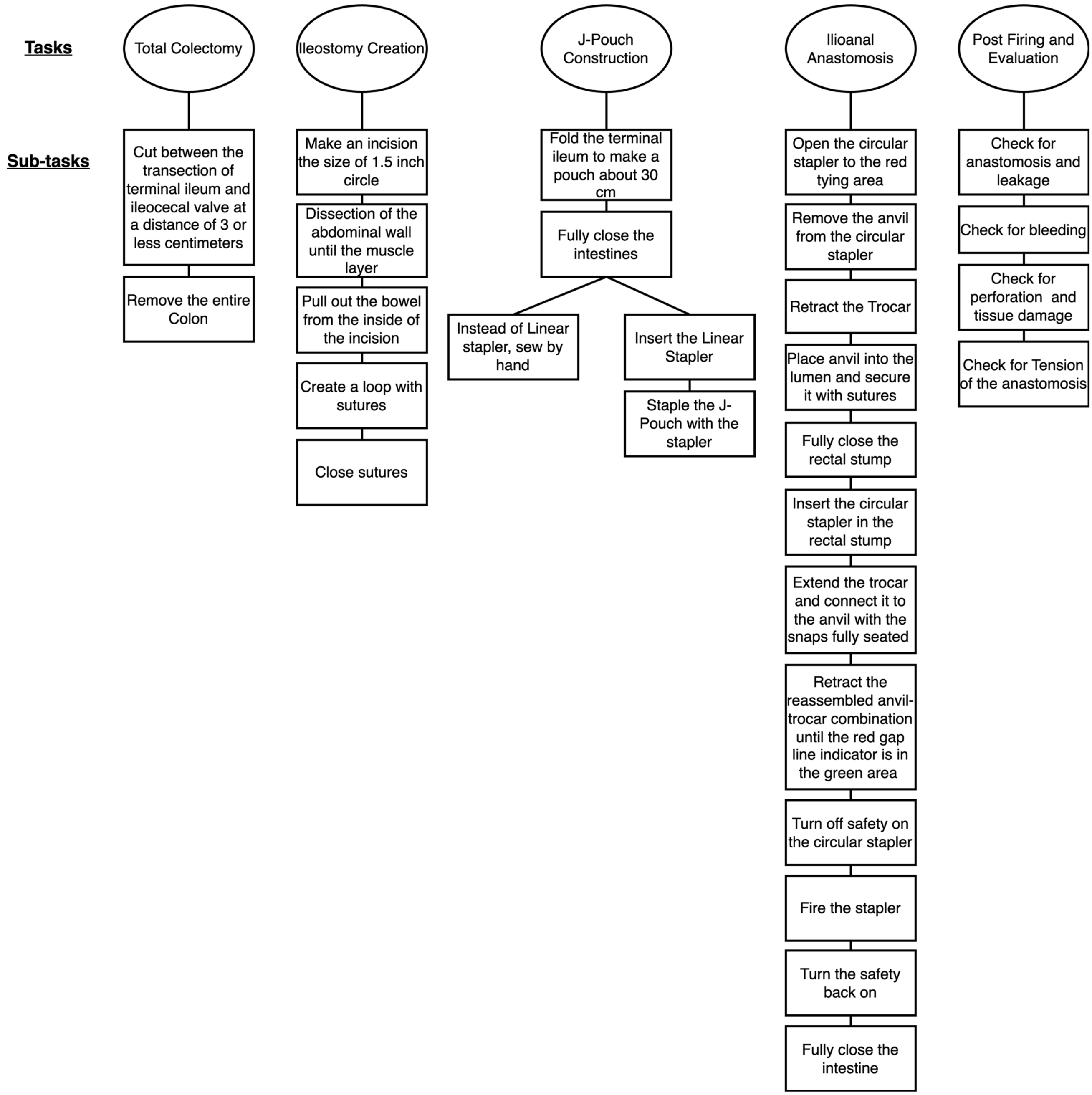

Fig. 3 Hierarchical task analysis tree with breakdown for execution

Performance metrics results

Initially, descriptive statistics and inferential comparisons were conducted across 19 performance metrics, including completion time and total score. These were automatically evaluated and recorded by the simulator. Shapiro–Wilk tests indicated that many performance metrics deviated from a normal distribution. Therefore, Mann–Whitney U tests were employed to compare experienced and novice performance. A significant difference in performance between experienced and novices in the assessment of J-pouch length was found, with experienced outperforming novices (3.67 [mean] vs. 1.50; $p = 0.01$). Experienced also outperformed novices on the gap indicator during trocar retraction (3.89 vs. 1.50; $p = 0.04$). Mean scores and standard deviations are summarized in Table 4. No statistically significant differences were observed for the remaining individual metrics, including total score (calculated as the sum of all metrics) and task completion time. However, experienced exhibited a trend toward higher total scores

Table 1 Tasks and subtasks description. For each metric, the simulator automatically gave a performance score of either 5 (excellent), 3 (average), or 0 (poor). Tool handling and suture handling were not included

Task	Subtask	Description
J-pouch construction	Fold bowel to make a J (in cm)	Fold the terminal 30 cm of ileum to make a J pouch about 15 cm
	Insert linear stapler	Insert stapler with jaws down each limb of the J
	Fire stapler twice	Fire the stapler twice to divide the entire septum between the limbs of the J
Ileoanal anastomosis	Purse suture	Make a purse string suture around the entire opening, alternating going in and out
	Anvil placement	Once the purse suture is completed, place the anvil of the circular stapler in the lumen of the J, and then pull the suture to secure it
	Circle stapler insertion	Insert the circular stapler through the anal canal and rectum
	Trocar extension	Extend the trocar and connect it to the anvil
	Gap indicator tension from trocar retraction	Keep an eye on the indicator so that retraction is stopped once the red line is within the green area on the indicator
	Turn off safety	To fire the stapler, disable the safety first
	Circle stapler firing	Fire the circle stapler once
	Safety back on	After firing, turn the safety back on
	Trocar extension and circle stapler removal from anus	Once the stapler is removed, extend the trocar slightly and remove
Post-firing evaluation	Check for leaks	Insert the insufflator device and check for leaks

Table 2 Perceptions of the simulator from the experienced group. Results are mean scores from a Likert scale from 1 to 5, with 1 meaning "not realistic at all" and 5 meaning "very realistic"

Question	Experienced Group (mean ± SD)
Degree of realism of the anatomy model	3.55 (1.12)
Degree of realism of the models and textures	3.27 (1.19)
Degree of overall realism of the simulator interface (instrument, model, and display)	3.36 (1.12)
Rate the realism of the force feedback	2.27 (1.27)
Rate the degree of realism of the task compared to the original task	2.45 (1.03)
Rate the usefulness of the force feedback	2.27 (1.34)

Table 3 Results of cognitive and physical workload assessment for both groups. Results are mean scores from each question of the NASA Task Load Index (NASA-TLX) survey

NASA-TLX Category	Experienced	Novice	*P* value
Mental demand	4.91	5.27	0.74
Physical demand	4.64	4.18	0.65
Temporal demand	4.00	4.27	0.79
Effort required	4.91	5.18	0.82
Frustration	4.82	3.82	0.37
Total	24.27	24.73	0.92

(76.33 vs. 70.50; $p = 0.1$) and faster procedure completion (670.1 ± 168.4 vs. 826.3 ± 189.7 s; $p = 0.094$), though these differences did not reach statistical significance.

Table 4 Mean scores and standard deviation (SD) of metrics that showed significance

Metric	Description	Experienced mean ± SD	Novice mean ± SD	*P* value
1	J-pouch length (14–16 cm)	3.67 ± 2.18	1.50 ± 1.58	0.0194
10	Gap indicator while trocar retraction	3.89 ± 2.20	1.50 ± 2.42	0.0477

Discussion

In this study, a novel VR simulator for the IPAA procedure was successfully developed and evaluated, addressing the lack of high-fidelity, risk-free training platforms for this operation. Results demonstrated that the simulator has evidence of validity, particularly for the J-pouch length measurement and gap indicator during trocar retraction, where significant differences were observed between experienced and novice participants. While experienced total scores and task completion times trended to be higher, these did not reach statistical significance. Experienced participants' perception results confirmed the simulator's anatomical realism and interface usability, supporting its potential value in surgical training and assessment. Particularly, subjective workload assessment using the NASA-TLX revealed similar cognitive and physical demands between groups, though novices reported slightly higher mental and effort-related strain. These findings suggest that the simulator provides a realistically challenging environment for learners across experience levels while still offering a feasible platform for repeated skills acquisition and performance evaluation.

The findings from this study align with a growing body of literature advocating for simulation-based training as a critical adjunct in surgical education [22–26]. Moreover, VR simulator-based training has been shown to improve technical performance, with several studies demonstrating and supporting its validity as an effective learning tool [9, 27–31]. Specifically for colorectal surgery, Sankaranarayanan et al. [32] conducted a study where a range of simulation tools available for training were reviewed, including physical, animal, cadaveric, and VR models, and the study highlights that simulation is increasingly essential for skill development, assessment, and quality improvement in both traditional and emerging colorectal procedures. Beyer-Berjot et al. [33] conducted a multicenter randomized study aiming to design and validate a VR-based competency-based curriculum for training in laparoscopic sigmoid colectomy. This study used the LAP Mentor simulator and included participants of varying levels of expertise where three key modules included performing a medial dissection, lateral dissection, and anastomosis as well as a full procedure. Performance metrics (time, number of movements, and path length) showed significant differences across experience levels, with novices demonstrating improvement through repetition, supporting the simulator's construct validity and effectiveness. Likewise, Shanmugan et al. [34] investigated which specific performance metrics demonstrated construct validity using the LAP Mentor simulator. From 21 metrics, 8 were found to reliably differentiate between general surgeons and expert colorectal surgeons, particularly instrument path length**,** peritoneal mobilization accuracy, and dissection of the inferior mesenteric artery. Our study aimed to contribute to the development of objective performance metrics for the IPAA procedure and their incorporation on a VR simulator that offers automated scoring, feedback, and infinite repeatability, which are critical features for achieving proficiency-based levels. This represents a significant step toward standardizing complex procedure training and assessment within general surgery and colorectal residency programs.

Our study had several limitations. First, the sample size was relatively small, limiting the statistical power to detect more subtle differences between groups. Despite statistically significant differences in select performance metrics, numerous measures remained consistent across experience levels. This may be attributed to participants in both groups completing an Altemeier procedure using the VCoST simulator immediately prior to the IPAA procedure. Additionally, several senior residents (PGY-3–5) had prior exposure to colorectal procedures during their rotations. These factors may have contributed to reduced performance differences between groups. Another limitation is that while the simulator was designed to mimic real-life tissue handling, VR-based haptic feedback still lacks the needed tactile fidelity, which could influence the translation of these skills to real-life tasks. Lastly, the absence of longitudinal performance tracking prevents the evaluation of skill acquisition over time, which is a critical component of validating simulation platforms.

Conclusion

In this study, we successfully developed and tested a VR simulator for the IPAA procedure and demonstrated initial construct validity, supporting its potential as a platform for skills training and proficiency-based assessment. By offering task repeatability, anatomy-specific interactions and automated scoring and feedback, this simulator addresses long-standing barriers in colorectal surgical training. As surgical training programs progressively shift toward competency-based frameworks, integrating validated simulation platforms like this one may improve trainee readiness, reduce learning curves, and ultimately improve patient safety. Future work will focus on longitudinal assessment to further define the role of VR-based simulation in colorectal surgical training.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00464-025-12406-9.

Acknowledgments The authors thank Dave Primm of the UT Southwestern Department of Surgery for help in editing this article.

Funding National Institute of Biomedical Imaging and Bioengineering, EB025241, Suvranu De.

Declarations

Conflict of Interest Drs. Garces-Palacios, Desir, Demirel, Salgado, Fleshman, De, and Sankaranarayanan, and Mr. Gopal, Westergaard, and Ellis have no conflicts of interest to disclose.

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