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Realism and Effectiveness of a Simulator Based on Realistic Gastric Morphology and Its Value in Training Novice Endoscopists

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Article

Keywords: Gastroscopy simulator, Simulation-based endoscopy training, Three-dimensional(3D) printing, Randomized controlled trial, Novice endoscopists

Posted Date: February 25th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-7631069/v1

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Additional Declarations: No competing interests reported.

Abstract

Traditional apprenticeship-based endoscopy training carries patient risk, while existing simulators have notable drawbacks. We developed a CT-derived, openable, 3D-printed gastric simulator that supports both diagnostic and therapeutic training, and evaluated its realism, validity, and educational impact for novices. Endoscopic procedures were recreated via modular tasks within the model. Thirty physicians of varying experience completed simulated operations; metrics included task time, errors, and 7-point Likert ratings of realism and usability. Educational effectiveness was tested in 30 novice trainees randomized to simulator training (Group A) or traditional mentoring (Group B), each receiving 12 h. Outcomes were operation time, DOPS scores across 14 domains, and 5-point Likert self-assessments. All endoscopists rated the simulator highly realistic, easy to use, low in physical/psychological burden, and motivating. Group A showed significantly higher subjective scores than Group B ($P < 0.05$), particularly for handling endoscopic instruments, clinical gastroscopy operations, understanding gastric anatomy, and confidence in examination. Our novel simulator can accurately replicate fundamental endoscopy techniques and effectively differentiate the varying levels of physician technical proficiency. Additionally, it offers advantages such as low cost, convenient and efficient operation, and reliability and safety, demonstrating a high potential for widespread adoption in gastroscopy teaching and training.

Introduction

Recent advancements in the endoscopic technology have revolutionized the treatment of various digestive diseases. Endoscopic methods that can be used for such diseases should offer dual benefits of maximizing patient comfort and minimizing pain and trauma[1,2]. Even though the majority of endoscopic methods are highly specialized and beneficial, their application in human bodies is complex and marked with complications[3-5]. To reduce these risks, it is essential to conduct a comprehensive training of endoscopists regarding the use of endoscopic methods so that endoscopists become adept in the use of these technologies. Traditional training methods, which involve direct training on patients under the supervision of a senior physician, carry inherent risks, such as an increased likelihood of gastrointestinal perforation resulting from additional endoscopic procedures[6,7]. Therefore, there is a need to develop suitable endoscopic simulator-based training methods for junior endoscopists before they can perform clinical operations.

Over the last decade, numerous simulators for training and evaluating endoscopic skills have been developed, including virtual reality models, animal models (both living and in vitro), and mechanical models. However, each type has its drawbacks. For instance, virtual reality simulators are expensive, often located away from clinical settings, and have complex operational procedures[8-10]. Animal models offer authenticity and practicality but come with challenges such as the need for special endoscopes, procurement of animal organs, and complexities in preparation and post-usage[11,12]. Many mechanical simulators, while convenient and affordable, are too abstract and lack anatomical accuracy. They fail to provide the realism necessary for effective training, especially for specialized endoscopic treatment techniques[13,14].This study aims to develop a novel endoscopic treatment simulator capable of accurately replicating gastric morphology and to perform a detailed evaluation of its realism and effectiveness[15]. In addition, we designed a clinical controlled trial to assess the value of our simulator in preclinical training for novice endoscopists.

Materials and Methods

Stage 1: Design and Construction of the Gastric Simulator Model

Skill Identification Assessment

Multiple endoscopic experts, junior medical students, and a 3D printing design team collaborated to identify the essential skills that every endoscopist should have. After a thorough review of professional association consensus, literature, and expert consultations, a comprehensive list of basic endoscopic skills was compiled (Table 1) [16-19]. As our basic stomach model allowed the simulation of only gastroscopy, we made it more capable by adding the necessary modules to simulate therapeutic procedures as well.

Prototype Design

Gastric Model: The process began with prototyping the upper digestive tract by 3D printing. CT images from anonymous volunteers were utilized. These images were imported into 3D slicer software (version 4.11.0, www.slicer.org) for a layer-by-layer construction of the basic model, which was then optimized and edited **(Fig. 1A)**. To enhance the practicality of the model and considering the necessities of 3D printing, we divided the model into three parts to ensure that it could open and close repeatedly with the help of magnetic fixed ring connectors **(Fig. 1B)**.

Task Training Modules: Two types of task training modules were developed for specific treatment operation simulations: 1) hollow cylinder modules, and 2) a writing pencil with an adhesive target paper.

Hollow Cylinder Modules: These modules, placed on the simulator's inner wall, represent standard gastric positions. They serve dual purposes: identification of the accurate position of trainees and facilitating training in specific endoscopic skills with different procedures, such as simulated gastric biopsy and snare polypectomy training **(Fig. 1C)**.

A Writing Pencil with an Adhesive Target Paper: This component can be attached to different positions inside the simulator using external magnets and is used in conjunction with a pencil fixed to a 1.2-meter hollow soft plastic tube, enabling the simulation operations of endoscopic submucosal

resection (ESD) **(Fig. 1D)**.

Enclosure Design: A specialized enclosure was developed to simulate the gastroscopy position of the human stomach for supporting and fixing the simulator to enhance training realism and efficacy **(Fig. 1E)**.

Printing and Assembly of Simulator

The designed files were imported into the printing software, using resin as the raw material for 3D printing. The gastric model was then assembled and placed in the external fixation enclosure **(Fig. 1F)**.

Stage 2: Trainer Evaluation and Testing

Tester Selection and Development of the Test Process

To evaluate the authenticity and effectiveness of the simulator, 30 diverse testers were selected and categorized as Novice Doctors, Junior Doctors, Intermediate Doctors, and Senior Doctors, based on their clinical endoscopy experience. The test processes included pre-test training for novices, test execution under supervision, recording and analyzing operations, and a post-test questionnaire. The tasks involved simulated gastric biopsy, snare polypectomy, and ESD operation **(Fig. 2A)**.

Simulated Gastric Biopsy and Snare Polypectomy Training

The testers began by inserting a gastroscope into a simulator, proceeding to each cylinder module in a fixed order. Biopsy forceps were inserted into the module holes, followed by ensnaring each module. The supervisors recorded the time taken at each simulation point, after the conclusion of the entire operation **(Fig. 2B, C&D)**.

Simulated ESD Procedure

The adhesive target paper was placed on the gastric antrum area of the simulator. The procedure involved simulating the cutting process by marking a full circle on the target paper with a writing pencil. The procedure ended once a circle was completed, and the supervisor photographed the target paper for analysis **(Fig. 2E)**. Error occurrences are counted by scanning the drawing path and the number of times it crosses the boundary **(Fig. 2F).**

Post-Test Questionnaire

The testers completed a self-administered questionnaire using a 7-point Likert scale to evaluate the authenticity, effectiveness, and practicality of the simulator (Supplementary Table 1).

Test Result Analysis

Subjects with varying levels of experience demonstrated significant differences in the time required to complete simulated gastric biopsy and snare polypectomy training. The difficulty across different anatomical sites was consistent with that observed in real clinical settings. For simulated ESD procedures, marked differences were observed among the groups in terms of operation time and error times. These findings confirm the practical utility of the simulator for training at various levels of professional expertise (Table 2 & Fig. 3).

Stage 3: Comparison of the Effects of Simulator and Traditional Clinical Mentoring Method for Skill Training Teaching of Gastroscopy Beginners

To further investigate the value of the simulator in real clinical settings, we randomly selected 30 physicians and divided them into two groups: Groups A and B. Group A consisted of 15 trainees who received training using the new simulated stomach model, while Group B had 15 trainees trained using the traditional “apprenticeship” clinical mentoring method. The learning curves and outcomes of the two groups before and after the training were compared.

Study Content

Thirty clinical physicians without prior experience in gastroscopy at Jingxing County Hospital, China, from September 2023 to October 2023, were selected as study subjects. One physician in Group B withdrew midway and was therefore excluded from the subsequent analyses. The average age of Group A (men = 5; women = 10) was 26.5±1.6 years. Group B (men = 5; women = 9) had an average age of 25.7±1.9 years. There were no statistically significant differences regarding age or gender between the two groups. A 5-point Likert scale questionnaire was used as the subjective rating standard. DOPS (Direct Observation of Procedural Skills) was used for objective assessment.

Inclusion Criteria: Clinical physicians without prior gastroscopy experience, who volunteered to participate and already possessed medical practitioner licenses.

Exclusion Criteria: Individuals who could not completely participate in the training or testing.

The study protocol was conducted in accordance with the principles of the Declaration of Helsinki. The acquisition of human data for this study was approved by the Ethics Committee of Jingxing County Hospital (No. 2023045). Oral or written informed consent was obtained from all participating trainees and patients.

Training Procedure and Assessment Method

Before Testing: All trainees spent the first 2 h in the gastroscope cleaning and disinfection area to familiarize themselves with the structure and function of the gastroscope, followed by another 2 h of basic theoretical knowledge and operational video lectures on gastroscopy. After completing this preliminary training, both groups underwent subjective assessments based on the 5-point Likert scale and, under supervision, each completed one clinical gastroscopy procedure for on-site DOPS assessment.

Operational Training and Testing: Each group underwent 12 h of gastroscopy operational training under the supervision of an instructor (1 h per session). Upon the completion of all training sessions, both groups were re-assessed using the subjective Likert scale and objective DOPS scoring. All clinical gastroscopies were performed under intravenous anesthesia. The exclusion criteria for patients were as follows: age below 20 or above 70, pregnancy, history of abdominal surgery, upper gastrointestinal bleeding, upper gastrointestinal obstruction, coagulopathies, and dysphagia. All patients provided informed consent for gastroscopy prior to the procedure. During the training and assessment, if the instructor deemed the operation to be risky, they would provide verbal instructions. If the trainee responded inadequately to the guidance or was unable to successfully complete the procedure even after three attempts, the instructor would take over the operation.

Examination Procedure with the New Simulated Stomach Model: Participants in Group A repeatedly used the new gastric simulator for endoscopy training. Locations such as the esophagus, cardia, gastric body, antrum, pylorus, and duodenal bulb were examined, and simulated biopsy with forceps and polypectomy training with a snare were conducted. The simulated stomach model contained multiple hollow cylinders at different locations to allow trainees to practice point-to-point precision insertion with biopsy forceps and snare. Adhesive target paper circle-drawing training can also be conducted to help trainees enhance their skill in fine endoscopic control.

Traditional Clinical Mentoring: In this type of training, the trainees were allowed to observe how the mentor operates an endoscope to understand the upper gastrointestinal anatomy and the corresponding endoscopic views to establish a spatial three-dimensional thinking of the digestive tract. Once the mentor completes gastroscopy, the trainee would practice withdrawing the endoscope from inside the patient, which would allow prompt correction of any improper techniques and explanation of the required skills. Finally, to learn how to maintain patient safety, the trainees gradually performed clinical gastroscopy under the instructor's supervision and guidance.

After Testing: After completing 12 h of training, both groups underwent a subjective assessment again using a 5-point Likert scale and independently performed a clinical gastroscopy procedure for on-site DOPS assessment.

Evaluation Instruments

A 5-point Likert scale questionnaire was developed to assess familiarity with how endoscopic procedures work, proficiency in endoscopic procedures, the use of endoscopic instruments, the structure of gastric anatomy and the confidence to perform clinical endoscopic procedures, with 5 representing "strongly agree" and 1 representing "strongly disagree" (Supplementary Table 1).

Clinical gastroscopy performance was evaluated using the DOPS assessment. The following 14 aspects were evaluated to simulate the practical circumstances as much as possible: endoscope handling skills, endoscope angulation and manipulation, suction of fluids and air and lens cleaning, insertion and withdrawal of the endoscope, observation of the esophagus, observation of the gastric body, fundus, antrum, observation of the greater curvature, lesser curvature, gastric angle, pylorus, duodenal bulb, and the descending section of the duodenum. If the instructor performed most of the tasks or decision-making and continuously provided verbal instructions, this was considered "full supervision," and the trainee was given 1 point. If the trainee required frequent intervention and verbal guidance, this was considered "intensive supervision," and given 2 points. If only occasional intervention or guidance was needed, this was "minimal supervision," and the trainee was given 3 points. If no supervision was required, this was deemed "independent," and the trainee was given 4 points. Scoring was conducted by a single associate chief physician with over 15 years of clinical endoscopy experience.

Results

Prior to training, none of the trainees in either Group A or Group B could independently complete clinical endoscopic examinations, and thus operation times could not be recorded. After training, the average gastroscopy operation time for trainees in Group A was 382 ± 167 s, while that for Group B was 543 ± 216 s ($P < 0.05$). Additionally, two trainees in Group A met patients with gastric polyps during clinical procedures and they successfully performed polyp biopsy operations. In contrast, one trainee in Group B was unable to independently complete the polyp biopsy operation.

Before training, 5-point Likert scale assessments of trainees' understanding of gastroscope operating principles, procedural proficiency, familiarity with endoscopic instruments, knowledge of gastric anatomy, and confidence in clinical examination showed that *P*-values were all greater than 0.05 between Groups A and B, indicating no statistically significant differences. After training, trainees in Group A scored 4.2 ± 0.7, 4.3 ± 0.6, and 3.8 ± 0.8,

respectively; whereas trainees in Group B scored 3.4 ± 0.6, 3.1 ± 0.5, and 2.6 ± 0.6, respectively ($P < 0.05$), indicating statistically significant differences (Table 3 & Fig. 4A).

Prior to training, assessments on endoscope control, endoscope bending control, aspirating liquids, air and lens cleaning, endoscope advancement and retraction, observation of the esophagus, gastric body, fundus, antrum, greater curvature, lesser curvature, gastric angle, pylorus, duodenal bulb, and duodenal descending segment afforded *P*-values greater than 0.05 for both Group A and Group B, indicating no statistically significant differences. After training, Group A demonstrated significant advantages over Group B regarding endoscopic control, observation of the fundus, antrum, gastric angle, pylorus, duodenal bulb, and duodenal descending segment, with *P*-values of less than 0.05, indicating statistically significant differences (**Table 4 & Fig. 4 B**).

Discussion

Multiple studies have shown that 3D printing, an advanced technology capable of generating 3D structures through computer-aided design, has proved to be highly useful in various fields[20-22]. Leveraging this advantage, we developed a new simulator using 3D printing to closely mimic the actual gastric structure[15]. Traditional simulators such as virtual endoscopic and animal tissue-based models, despite their effectiveness, are limited by high costs, continual management, and repeatability issues[23-26]. Our simulator does not have these limitations, as it allows flexible, ethical, and cost-effective endoscopy training. It is portable, weighs 3 kg, measures only 50 cm, and the cost of printing materials is only 30 USD. In addition, it offers advantages such as convenience, authenticity, and durability and supports a wider range of therapeutic endoscopic operations, showcasing its significant potential for development.

Experiments conducted with participants of varying experience levels have validated the effectiveness and realism of our simulator. Compared to experienced endoscopists, novices required more time to complete the training and demonstrated lower performance quality, indicating that this model has the potential to assess an endoscopist's skill. All endoscopists, including both beginners and experienced, provided positive feedback, further confirming the effectiveness of the simulator in improving the fundamental endoscopic skills and reducing patient risk. Therefore, this simulator is regarded as a highly valuable training tool.

We also performed a comparative analysis, in which the new simulation model for endoscopic training was compared with traditional methods. The group trained with the novel simulator scored significantly higher than the group trained using traditional teaching methods in familiarity with endoscopic instruments, understanding of stomach structure and clinical examination confidence level. After training, the clinical procedure times of the group trained on our simulator were shorter, and their DOPS scores were markedly better than those of the control group. This can be mainly attributed to the ability of the model to perform a realistic simulation of gastric anatomy and therapeutic procedures such as biopsy and polypectomy training, which enables trainees to practice repeatedly and quickly master essential techniques. Endoscopists must possess advanced endoscopy skills so that they can handle complex stomach issues in practical medical settings. Our simulator offers specific training for these situations, with more realistic representations of different parts of the stomach such as the fundus and angles, which are not as well depicted in older models. The enhanced anatomical accuracy of our simulator allows successful performance of endoscopic procedures and supports in training as well.

While our simulator affords greater training efficiency and convenience, it has certain limitations as well, such as the lack of esophageal insertion training and inability to simulate stomach dynamics. To address these issues, we plan to develop a soft rubber simulator to further enhance realism in our next studies.

Conclusion

Our gastric morphology simulator marks a significant advancement in endoscopic training. Characterized by its powerful simulation capabilities, this tool excels in providing training regarding basic endoscopic skills. It stands out for its repeatability, convenience, and authenticity, effectively simulating various endoscopic treatment techniques for more realistic training experiences. Additionally, as a standard tool, the novel simulator could serve as a metric to assess the technical proficiency of endoscopists. Notably, training with this simulator can significantly enhance the operating skills of novice endoscopists, while also providing valuable training opportunities for endoscopists specializing in therapeutic endoscopy. Our 3D-printed gastric simulator is an efficient, realistic training tool that can significantly enhance the skills of endoscopists at a low cost and effectively prepare them for clinical endoscopy.

Declarations

Fundings:

This work was supported by the Key R&D Program of Henan Province (No. 231111311600), Zhongyuan talent program (ZYYCYU202012113) and Zhengzhou Science and Technology for the People Project (2024KJHM0019)

Data availability statement

The datasets generated during and/or analyzed during the current study are not publicly available due to including personal medical information. But the datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgement

We thank Medjaden Inc. for scientific editing of this manuscript. This work was supported by the Key R&D Program of Henan Province (No. 231111311600), Zhongyuan talent program (ZYYCYU202012113) and Zhengzhou Science and Technology for the People Project (2024KJHM0019)

Competing interests

No potential conflict of interest relevant to this article was reported.

Author contributions

Study concept and design: B.R.L. Data acquisition: J.Y.Z., Q.H.G., Q.F.Z., M.S. Data analysis and interpretation: J.Y.Z, Z.Y.S. Drafting of the manuscript: J.Y.Z Critical revision of the manuscript for important intellectual content: Q.H.G., D.L. Statistical analysis: Z.Y.S. Obtained funding: B.B.R., D.L., B.R.L. Administrative, technical, or material support; study supervision: J.P.F., D.L., B.R.L. Approval of final manuscript: all authors.

Additional information

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Tables

Table 1. Time-consuming operations of simulated gastric biopsy and simulated polyp snare resection at different lesion positions

	Simulated Gastric Biopsy					Simulated Snare Polypectomy				
Lesion Location	Novice (*n* = 10)	Junior (*n* = 10)	Intermediate (*n* = 6)	Senior (*n* = 4)	*P*-value	Novice (*n* = 10)	Junior (*n* = 10)	Intermediate (*n* = 6)	Senior (*n* = 4)	*P*-value
1 PW of GF	173.4±157.7	67.1±40.1	27.3±13.0	20.5±2.2	0.013	134.6±103.4	99.9±65.6	40.5±20.7	12.3±0.8	0.023
2 AW of GF	54.3±41.1	33.9±17.2	19.5±7.1	14.3±2.0	<0.001	133.1±111.7	45.8±30.4	33.2±15.8	11.3±1.3	0.009
3 LC of GF	53.0±29.6	33.7±20.1	13.5±5.6	18.5±2.1	<0.001	101.6±81.1	57.7±40.1	22.0±7.7	10.8±0.8	0.001
4 GC of GF	59.1±33.1	69.6±36.4	34.5±24.5	17.0±2.2	0.003	143.6±100.7	101.6±81.7	46.8±30.0	21.3±2.5	0.004
5 Fundus	33.7±15.3	29.7±10.9	19.2±10.0	6.2±0.4	<0.001	54.0±30.9	43.4±23.5	31.3±17.1	15.8±1.9	<0.001
6 AW of GB	46.3±25.7	32.2±22.3	19.3±19.7	5.8±0.8	0.009	45.4±38.2	41.8±21.3	20.5±13.7	13.8±0.4	0.003
7 LC of GB	129.0±85.3	67.2±38.8	31.8±17.9	9.5±0.5	<0.001	117.7±84.8	59.1±27.0	30.5±15.3	12.8±1.1	<0.001
8 PW of GB	75.8±50.0	40.2±33.4	14.5±7.2	12.8±1.5	0.002	94.2±89.5	54.1±27.7	31.0±12.2	17.5±1.8	0.004
9 GC of GB	52.1±48.4	30.8±30.0	9.8±5.2	8.0±0.7	0.007	34.3±12.6	34.1±15.7	21.0±8.5	8.3±1.3	<0.001
10 Antrum	84.0±65.4	45.0±22.5	20.3±8.8	8.0±0.7	0.002	88.5±57.5	59.8±35.3	29.5±13.1	10.3±1.5	<0.001
11 PW of GA	59.0±64.3	36.7±25.9	10.3±3.1	8.0±0.0	0.003	80.0±58.5	55.7±39.4	19.5±14.3	10.0±0.7	0.001
12 GC of GA	56.5±23.7	41.8±28.7	12.7±4.7	9.5±0.5	<0.001	46.0±27.3	34.4±18.0	22.3±12.7	10.3±0.8	<0.001
13 AW of GA	179.2±118.8	115.4±95.9	34.0±13.4	24.8±3.6	<0.001	62.2±43.1	114.9±123.0	24.3±10.1	13.5±3.3	0.003

PW, posterior wall; GF, gastric fundus; AW, anterior wall; LC, lesser curvature; GC, greater curvature; GB, gastric body; GA, gastric antrum

Table 2. Seven-point Likert Scale

Table 3. Five-point Likert scale score of subjectivity of the two groups before and after training

	Novice (*n* = 10)	Junior (*n* = 10)	Intermediate (*n* = 6)	Senior (*n* = 4)
1. The model has high authenticity	6.8±0.3	5.8±1.0	5.7±0.9	6.0±0.0
2. It is convenient to use this model for training	6.8±0.4	6.2±0.7	6.3±0.7	6.5±0.5
3. High interest and good spirit during use	6.6±0.7	6.4±0.7	6.2±0.9	6.0±0.4
4. No fatigue and low body load during use	5.9±1.0	6.0±0.8	5.5±0.8	6.3±0.4
5. Control of gastroscope	6.2±1.2	6.5±0.7	6.0±0.7	5.5±0.5
6. Use of biopsy forceps	6.2±0.9	6.5±0.7	5.8±0.7	5.5±0.7
7. Use of snares	6.0±1.1	6.7±0.7	5.8±0.7	5.7±0.4
8. Tacit cooperation with the console assistant	5.8±1.1	6.7±0.6	6.3±0.7	6.0±0.7
9. The risk of patients can be reduced by training the novice with the simulator before clinical operation	6.5±0.9	6.6±0.7	6.8±0.4	6.8±0.4
10. I suggest using this simulator in gastroscope operation training	6.6±0.7	6.8±0.4	6.5±0.8	6.8±0.4

	Before Training			After Training		
	Group A (*n* = 15)	Group B (*n* = 14)	*P*-value	Group A (*n* = 15)	Group B (*n* = 14)	*P*-value
Understanding how it works	1.4±0.5	1.4±0.5	0.815	4.6±0.5	4.2±0.5	0.095
Proficiency in the operation process	1.3±0.5	1.2±0.4	0.596	4.4±0.6	4.0±0.6	0.073
Familiarity with endoscopic instruments	1.2±0.4	1.2±0.4	0.926	4.2±0.7	3.4±0.6	0.005
Understanding of stomach structure	1.1±0.4	1.1±0.5	0.419	4.3±0.6	3.1±0.5	<0.001
Clinical examination confidence level	1.2±0.4	1.2±0.4	0.926	3.8±0.8	2.6±0.6	<0.001

Table 4. Direct Observation of Procedural Skills (DOPS) score before and after training

Evaluation Content	Before Training			After Training		
	Group A	Group B	*P*-value	Group A	Group B	*P*-value
Endoscope control	1.20±0.42	1.30±0.48	0.626	3.40±0.52	2.60±0.84	0.020
Endoscope bending control	1.10±0.32	1.20±0.42	0.557	3.50±0.53	3.30±0.48	0.388
Aspirating liquids, air, and lens cleaning	1.30±0.48	1.20±0.42	0.626	2.70±0.48	3.30±0.67	0.034
Endoscope advancement and retraction	1.70±0.48	1.60±0.52	0.660	3.70±0.48	3.60±0.52	0.660
Esophageal observation	1.60±0.52	1.80±0.42	0.357	3.50±0.71	3.30±0.48	0.470
Gastric body observation	1.50±0.53	1.60±0.52	0.675	3.40±0.52	3.00±0.67	0.153
Fundus observation	1.20±0.42	1.10±0.32	0.557	2.90±0.57	2.10±0.88	0.027
Gastric antrum observation	1.30±0.48	1.40±0.52	0.660	3.40±0.52	2.60±0.70	0.033
Greater curvature observation	1.40±0.52	1.60±0.52	0.401	3.20±0.63	2.70±0.48	0.061
Lesser curvature observation	1.20±0.42	1.40±0.52	0.357	3.30±0.67	2.70±0.67	0.061
Gastric angle observation	1.10±0.32	1.20±0.42	0.557	3.40±0.52	2.30±0.48	<0.001
Pyloric observation	1.20±0.42	1.10±0.32	0.557	2.90±0.74	2.00±0.82	0.019
Duodenal bulb observation	1.10±0.32	1.20±0.42	0.557	2.40±0.97	1.50±0.53	0.019
Descending segment of duodenum observation	1.10±0.32	1.10±0.32	1.000	2.10±0.74	1.30±0.48	0.010

Figures

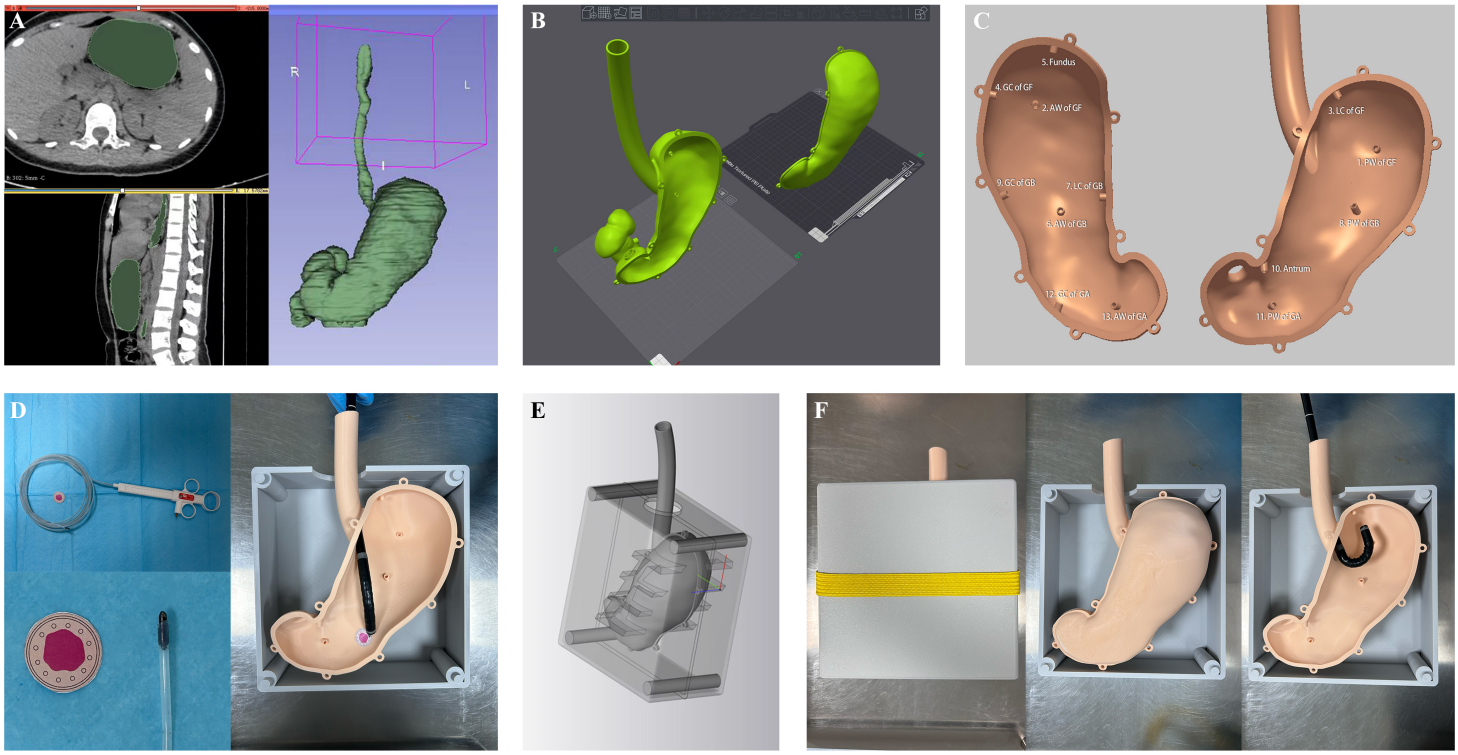


Figure 1

(A) Basic model of the upper gastrointestinal tract constructed using Slicer software. (B) Optimized prototype of the model refined with Blender software and segmented into three distinct parts using Geomagic Design X software. (C) Hollow cylinder modules strategically positioned at various anatomical locations within the gastric model. (D) Incorporation of adhesive target paper and a writing pencil for marking. (E) A specialized enclosure was developed to simulate the gastroscopy position of the human stomach. (F) Fully assembled training simulator, complete with an enclosing structure.

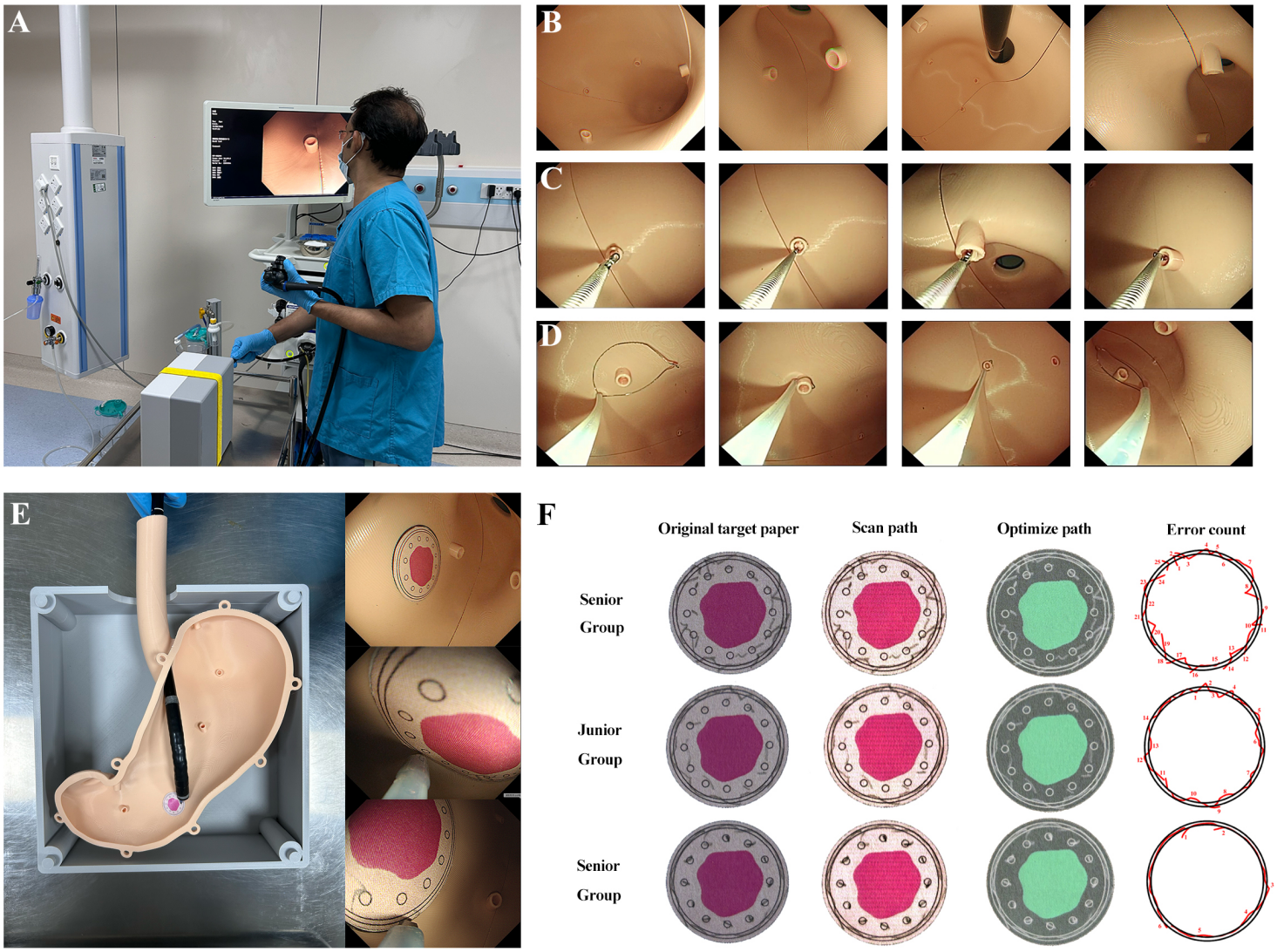


Figure 2

(A) Representation of a test operation scenario. Gastroscopic views for (B) simulator, (C) simulated gastric biopsy, (D) simulated snare polypectomy, and (E) simulated ESD procedure. **(**F) Digital processing and analysis of training outcomes.

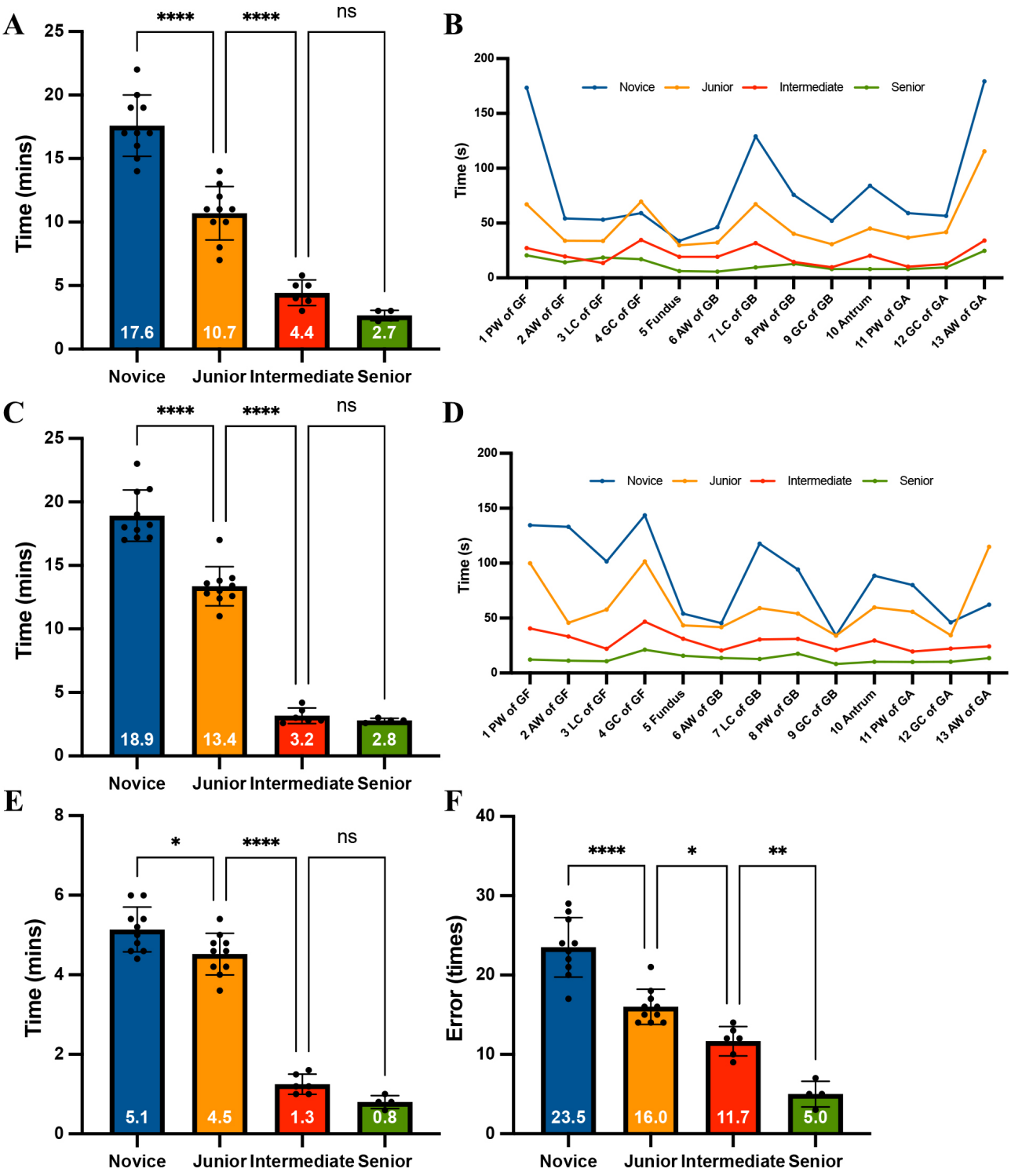


Figure 3

Average time of (A) simulated gastric biopsy in different groups, (B) simulated gastric biopsy at different points, (C) simulated snare polypectomy in different groups, (D) simulated snare polypectomy at different points, (E) simulated ESD procedure in different groups and (F) operation errors of simulated ESD procedure in different groups.

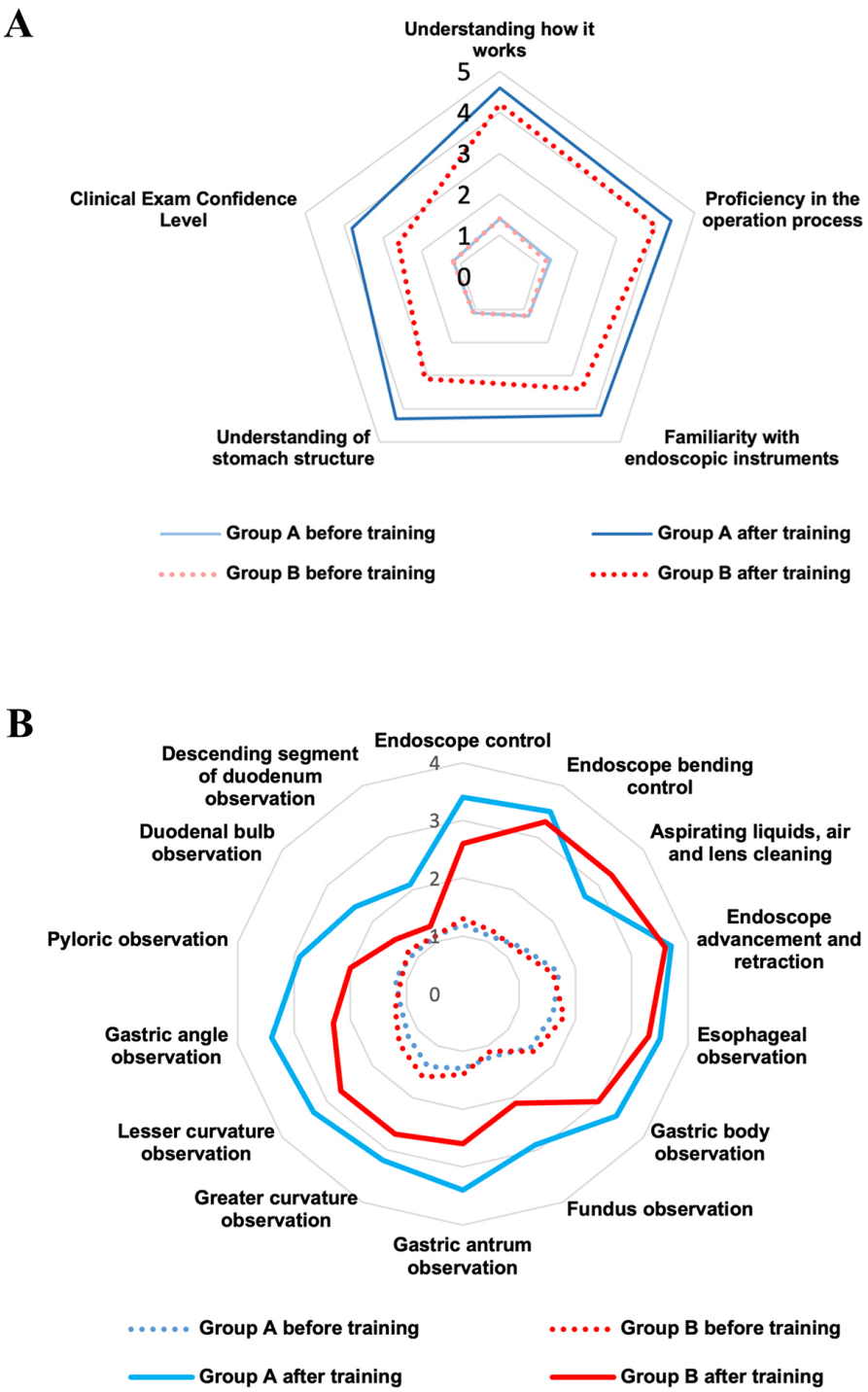


Figure 4

(A&B) Radar charts depicting subjective and objective evaluations of two the groups before and after training, comparing both training methods.

Supplementary Files

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- Supplementary.docx