

Impact of Simulation-Based Training on Camera Angulation Skills in Novice Laparoscopists: A Randomized Controlled Study

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Abstract

Background: Effective camera handling is fundamental to laparoscopic surgery, yet structured training in camera angulation is often underemphasized in early Minimal Invasive Surgery (MIS) education. This randomized controlled study evaluated the impact of angle-specific simulation training on novice performance across three clinically relevant trocar entry points. **Methods:** Twenty medical trainees with no prior MIS experience were randomized to a simulation-trained group or a theory-only control group. The study group completed fifteen structured sessions (five per angle), while controls received only a baseline lecture. All participants performed standardized bean-transfer tasks under Umbilical, Palmer's Point, and Lee-Huang angles. Outcomes included task completion time, error patterns, and camera stability; subjective ratings assessed visualization and spatial orientation. Semi-structured interviews explored cognitive adaptation. **Results:** Sixteen participants completed the study. The simulation group achieved significantly faster task times across all five sessions compared with controls (all $p < 0.001$). Mixed-ANOVA confirmed strong between-subject (FBSE = 81.632, $p < 0.001$), within-subject (FWSE = 55.851, $p < 0.001$), and interaction effects (FIE = 8.528, $p < 0.001$), indicating robust training-related improvement. Angle-specific analysis demonstrated significant improvements across all camera positions, with the greatest efficiency observed at the umbilical angle and the highest difficulty at Palmer's Point. Subjective ratings favored the umbilical angle in instrument control ($p = 0.017$), spatial orientation ($p = 0.038$), coordination ($p = 0.011$), and overall

task ease ($p = 0.001$). Qualitative analysis identified three themes: initial cognitive strain at off-axis views, progressive visuospatial adaptation with repetition, and distinct angle-specific learning curves. **Conclusion:** Structured camera-angle simulation training significantly enhances speed, accuracy, and stability in laparoscopic visualization tasks, while improving novices' spatial orientation and confidence. Early integration of angle-specific modules into MIS curricula may accelerate visuospatial readiness and improve foundational operative skills.

Keywords

Laparoscopic Training, Camera Angulation, Simulation-Based Education, Minimally Invasive Surgery

1. Introduction

Minimally invasive surgery (MIS) has transformed operative practice by reducing postoperative pain, accelerating recovery, minimizing tissue trauma, and improving cosmetic outcomes [1]. Central to the effectiveness of MIS is the acquisition of high-quality intra-abdominal visualization through laparoscopic cameras. Unlike open surgery, where surgeons rely on direct three-dimensional sight and tactile feedback, laparoscopy limits the operative field to a two-dimensional screen, requiring practitioners to master camera manipulation, image interpretation, and spatial orientation through indirect visual cues [2] [3]. As numerous authors [4] have emphasized, visualization-related errors account for a significant proportion of challenges faced by novice surgeons during early MIS exposure, and these difficulties can hinder safe tissue handling, increase operative time, and compromise procedural flow (various surgical education studies highlight this relationship).

Camera angulation, specifically the placement and orientation of the laparoscopic trocar serving as the entry point for the camera, plays a pivotal role in determining the stability, field of view, and effective working area of the surgeon. Traditional laparoscopic training emphasizes instrument handling and coordinated movements, but often neglects the detailed understanding of how trocar site selection influences the visual field. Several studies [5] [6] in the broader surgical simulation literature have suggested that the choice of camera entry point alters aspects such as the effective angle of approach, light reflection, depth perception, and ability to maintain a stable horizon. While these findings are widely acknowledged among experienced surgeons, structured exposure to different camera angulations is seldom incorporated into early training programs for medical students and interns. Historically, novice learners receive much of their camera experience in the operating room, where they are expected to support the primary surgeon by holding and adjusting the camera. However, as educational researchers have noted [7], this apprenticeship-style exposure frequently lacks con-

sistency, trainees may receive little instruction on ideal camera placement, and learning is influenced by the demands of the surgery rather than the learner's needs. This creates a gap between expectations and actual skill acquisition. In particular, learners rarely develop a conceptual understanding of how trocar position affects visual access to superior, inferior, lateral, or retroperitoneal structures. The resulting steep learning curve can diminish confidence, produce disorientation during off-axis visualization, and prolong procedures.

Three trocar positions are widely used in general surgery, gynecology, and foregut procedures because they provide distinct visual perspectives that influence operative access and camera handling demands. These include: 1) the Umbilical (midline) entry point, which offers a central and intuitive viewing axis; 2) Palmer's Point in the left upper quadrant, commonly utilized when midline access is unsafe or restricted; and 3) the Lee-Huang Point in the mid-upper abdomen, which provides a higher vantage point for pelvic and upper abdominal visualization.

Although each of these angles plays an essential role in clinical practice, the relative difficulty that novices experience when adapting to these differing viewpoints has not been systematically examined under controlled simulation conditions. Most existing studies [8] [9] assessing camera skills rely on single-angle testing or focus predominantly on the technical ease of port insertion rather than on the learner's cognitive adaptation to altered visual perspectives. As a result, the educational implications of training across multiple camera angles remain poorly understood.

Simulation-based training has emerged as a safe and effective method for building foundational laparoscopic skills [10]. Its strengths include the ability to standardize tasks, provide repetitive structured practice, reduce variability introduced by clinical environments, and allow learners to reflect on performance without patient risk. Several investigations into simulator-based curricula have shown improvements in hand-eye coordination, depth perception, and camera navigation for novices [11]. However, very few studies [12] [13] have systematically examined whether exposure to multiple trocar positions enhances the trainee's ability to adjust to different fields of view, nor have they compared outcomes between learners who receive structured practice and those who receive only theoretical instruction. There is a compelling pedagogical rationale to do so. Off-axis camera angles, such as Palmer's Point require the operator to mentally rotate and reinterpret visual information because the horizon is shifted and anatomical structures are viewed from nontraditional directions. Research on spatial cognition suggests that such tasks require higher-order mental rotation skills, which can be significantly improved through targeted, repetitive practice [14]. Conversely, failure to train these skills early may lead to difficulty when trainees eventually encounter complex angles in the operating room.

Given this background, our study was designed to evaluate the extent to which structured simulation-based training on three clinically relevant camera angles af-

fects novice laparoscopic performance. Such analysis will provide potential implications for curricular design in medical education, especially in contexts where early and safe exposure to surgical visualization is essential.

2. Methods

2.1. Study Design

This prospective, randomized, single-blinded experimental study was conducted at the Simulation and Surgical Skills Training Centre of Zhejiang Provincial People's Hospital over four weeks. The study followed methodological principles used in previous laparoscopic skills research, including the structured simulation approaches described by Seymour *et al.* [15] and Van Sickle *et al.* [16], with modifications tailored to camera-specific training. The protocol was designed to evaluate the effect of simulation-based exposure to three standardized laparoscopic camera angles on the acquisition of visuospatial and camera manipulation skills among novice trainees.

All participants provided written informed consent and agreed to comply with the study schedule. The study followed a pre-test/post-test framework, allowing both within-group and between-group comparisons, and adhered to CONSORT recommendations for reporting randomized trials [17]. The study design and participant flow are summarized in **Figure 1**. Eligible novice medical students were randomly allocated to either the training or control group. Both groups completed baseline and repeated assessment sessions, while the intervention group additionally underwent fifteen structured simulation-training sessions during the study period.

2.2. Participants

A convenience sample of twenty undergraduate clinical-year medical students (3rd-5th year) was recruited. Eligibility screening confirmed that participants had no prior exposure to laparoscopic simulation, minimally invasive surgical training, or MIS workshops. Twenty-four students initially expressed interest, of whom four were excluded due to scheduling conflicts, leaving twenty eligible participants who were randomized into study and control groups.

During the trial, four participants (three in the study group and one in the control group) were withdrawn due to repeated absenteeism (missing > 2 scheduled sessions). The final analysis was therefore conducted on a per-protocol basis, including only participants who completed all study procedures. A total of 16 participants were included in the final analysis (study group, $n = 7$; control group, $n = 9$).

Although these post-randomization withdrawals may have influenced group balance given the small sample size, baseline characteristics, including age, gender, year of study, hand dominance, laparoscopic interest, and prior simulator experience, remained comparable between groups, as shown in **Table 1**.

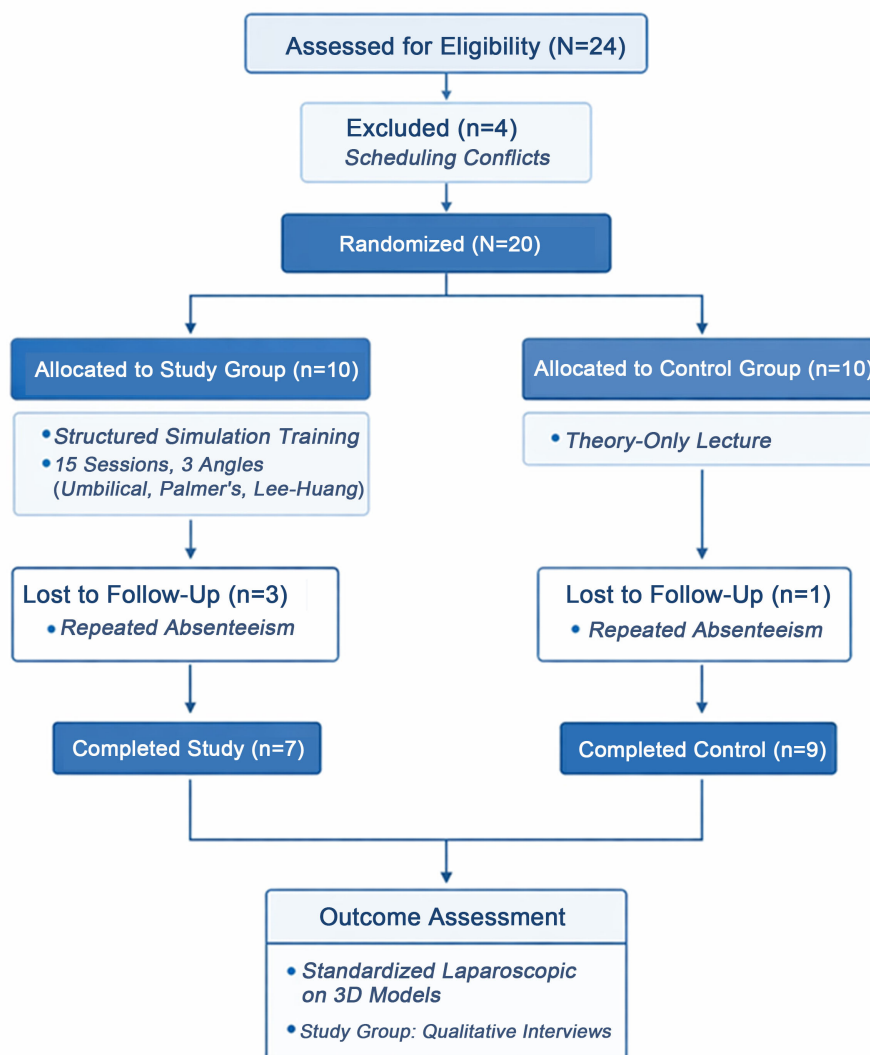


Figure 1. Study flowchart showing participant recruitment, screening, randomization, withdrawals, and final analysis.

2.3. Baseline Orientation and Pre-Training Assessment

Before randomization, all participants attended a structured 45-minute introductory lecture that provided foundational knowledge necessary for the study. This session covered the principles of minimally invasive surgery, the mechanics of instrument handling and ergonomic posture, and core visuospatial concepts such as depth perception and the fulcrum effect. Participants were also introduced to the basics of laparoscopic camera operation, including horizon control and maintenance of a stable visual field. To reinforce these concepts, a brief demonstration video illustrating fundamental laparoscopic visualization tasks was shown to all participants. After the lecture, students completed a seven-item knowledge quiz designed to ensure a uniform theoretical baseline before pre-testing; only those who achieved a perfect score proceeded to the next phase of the study.

Table 1. The baseline characteristic for participants.

Characteristic	Study group	Control group
Age	24.00 ± 3.21	24.44 ± 2.40
Gender		
Female	4	5
Male	3	4
Year of study		
3rd	2	1
4th	3	5
5th	2	3
Hand Dominance		
Right	7	9
Left	0	0
Laparoscopic interest		
Yes	7	9
No	0	0
Experience with simulators (box trainers or VR)		
Yes	0	0
No	7	9

2.4. Randomization and Group Allocation

Randomization was performed using a computer-generated sequence in a 1:1 ratio. Each participant received a unique identification number, and group assignments were secured using sealed opaque envelopes opened at the first session. Due to the nature of the intervention, participant blinding was not feasible. However, video-based scoring was performed by a single blinded expert reviewer, who was unaware of group assignments, ensuring assessor blinding and reducing bias.

2.5. Training Equipment

The training was conducted using two primary laparoscopic simulation systems. The first was the Laparoscopic Simulation Trainer 200-E, manufactured by Shanghai Rushing Laboratory Equipment Co., Ltd., which served as the foundational platform for developing basic laparoscopic handling skills. Following the initial phase, participants progressed to a portable Laparoscopic Sim Box equipped with advanced 3D-printed task models, allowing practice under varied camera angulations and facilitating suturing exercises with enhanced spatial realism (**Figure 2**) [18].

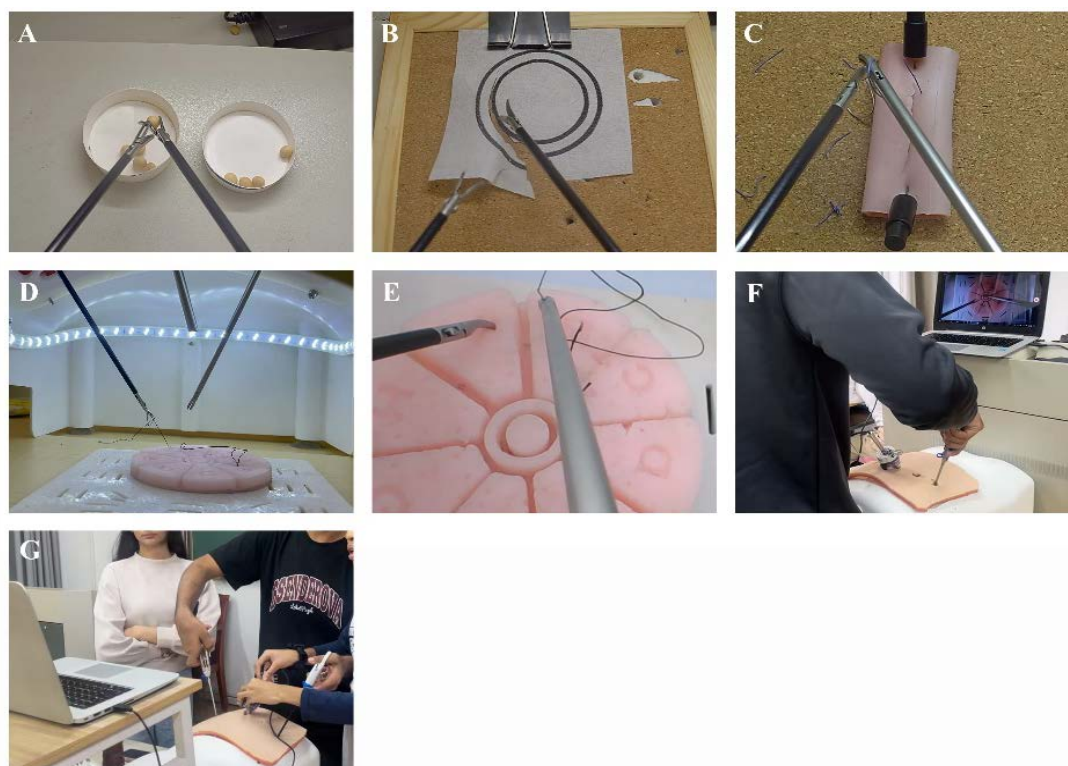


Figure 2. Laparoscopic simulation tasks and training setup illustrating the structured progression of simulation tasks used to develop core laparoscopic skills, including object transfer, cutting, camera angulation exercises, and intracorporeal suturing on 3D-printed models. (A) Bean transfer task between stations to improve hand dexterity using Maryland dissector and grasping forceps. (B) Precision cutting task using laparoscopic scissors and Maryland instrument under timed assessment. (C) Tissue manipulation and demonstration of intracorporeal suturing using Maryland grasper and needle holder. (D) Triangulation principle during camera holding and suturing practice. (E) Knot tying under different camera angles. (F-G) Portable 3D simulator box models used for repetitive laparoscopic skills training.

2.5.1. Training Tasks

The curriculum was structured into four progressive tasks (**Figure 2**). Task 1 focused on basic hand-eye coordination and instrument handling through repeated bean-transfer exercises performed ten times, analogous to peg transfer drills [19]–[21]. Task 2 advanced to precision cutting tasks using laparoscopic scissors and graspers. Task 3 introduced camera angulation and visualization strategies under different viewing perspectives. Task 4 emphasized intracorporeal suturing and knot tying using 3D-printed tissue models. Standardized camera positions used during angle-specific training are illustrated in **Figure 3**.

2.5.2. Camera Angulation Conditions

Three clinically relevant camera angles were used to assess variation in laparoscopic visualization: the Umbilical (midline) entry, which offers a direct and intuitive visual axis with minimal distortion [22]; Palmer’s Point in the left upper quadrant, which produces a lateral off-axis view associated with increased visuospatial and cognitive demands [23]; and the Lee-Huang Point in the mid-upper abdomen, which provides a superior vantage point with moderate non-linear distort-

tion [24]. All trocar locations were pre-positioned on the trainer for standardized replication, and the order of angles during post-testing was randomized to reduce sequence-related bias. The 3D simulator box was equipped with multiple ports to allow camera insertion at these standardized positions, including the umbilical, Lee-Huang, and Palmer's Point locations, as illustrated in **Figure 3**.

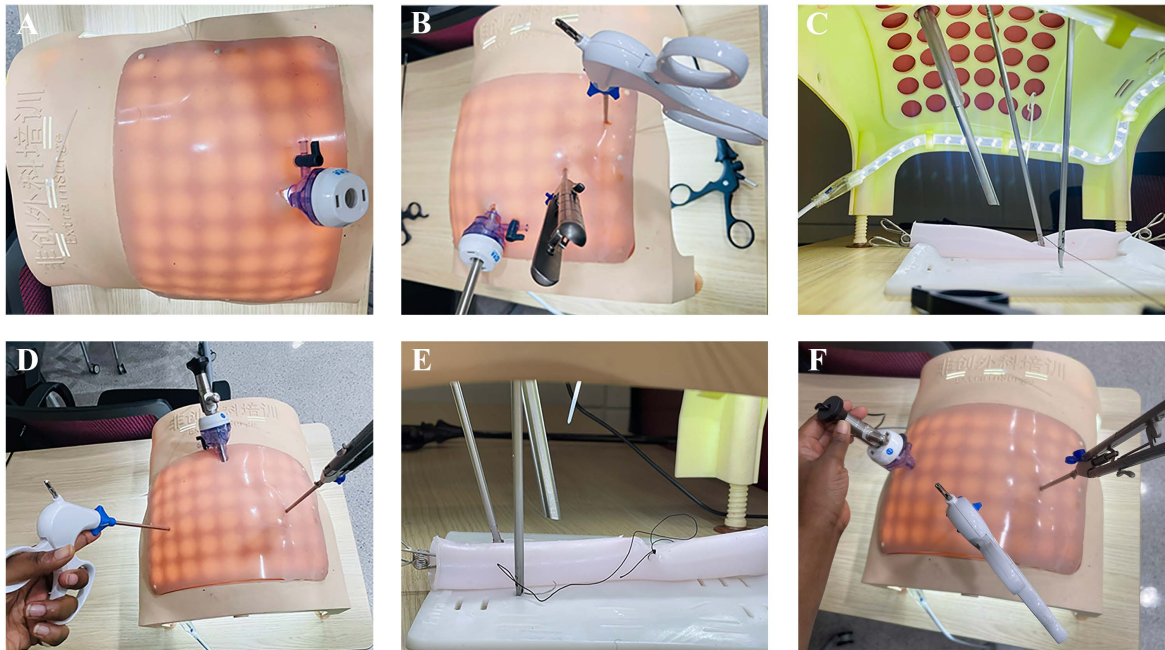


Figure 3. Standardized simulation setup for angle-specific laparoscopic camera training demonstrating the standardized simulator setup, trocar placement, and camera orientation corresponding to the three tested viewing angles: umbilical, Palmer's Point, and Lee-Huang Point. (A) Simulator box with multiple camera insertion ports. (B) Left upper quadrant camera position (Palmer's Point) on the 3D model. (C-D) Umbilical camera port insertion with ipsilateral instrument alignment. (E) Lee-Huang Point (mid-upper abdomen) demonstrating triangulation principles. (F) Camera adjustment to optimize exposure and visualization.

2.6. Training Protocol

2.6.1. Study Group

The study group underwent a structured simulation-based curriculum consisting of fifteen supervised sessions, with five sessions dedicated to each camera angle. Each session lasted approximately 15 minutes and followed a standardized instructional sequence that included a brief orientation to the assigned angle, a short warm-up period to stabilize the camera and familiarize participants with the visual field, a focused bean-transfer visualization task performed under the designated angle, and a brief debriefing emphasizing horizon leveling, target acquisition, and image stability. To maintain methodological rigor, assistance from the instructor was minimal during task execution, thereby reducing coaching bias and ensuring that improvements reflected genuine skill acquisition.

2.6.2. Control Group

The control group received a single 45-minute theoretical lecture covering the

principles of laparoscopic visualization, including depth perception, camera stability, and fulcrum mechanics, without structured hands-on training. This approach reflects the traditional imbalance in early surgical education, where trainees often receive theoretical instruction without equivalent practical exposure, and aligns with “lecture-only” comparator models used in previous minimally invasive surgery training studies [25].

To allow comparison of performance trends over time, participants in the control group performed the same standardized assessment tasks at matched time intervals but did not receive structured training or feedback between sessions.

2.6.3. Study Timeline

The study followed a structured timeline. All participants first completed a baseline assessment of camera-handling performance across the three camera angles (umbilical, Palmer’s Point, and Lee-Huang), using the standardized simulator setup shown in **Figure 3**. Following randomization, the intervention group completed fifteen simulation sessions (five per camera angle) over the study period, while the control group did not undergo structured training. Performance assessments were conducted at five predefined time points to evaluate progression over time. Both groups then completed a final post-intervention assessment using identical tasks and outcome measures.

2.7. Performance Assessment

Performance was assessed at both baseline and post-training using the same standardized laparoscopic task [26] for all participants. The primary assessment consisted of a modified peg-transfer drill designed to evaluate essential components of camera handling and visuospatial control. During the task, participants were required to manipulate the laparoscopic camera with one hand while maintaining a level horizon, preserving continuous visualization of the target field, demonstrating accurate depth perception, and completing object transfers without losing sight of the operative area. A single, uniform task template was used throughout the study to ensure consistency across all assessments and to minimize variability between participants and testing sessions.

2.8. Outcome Measures

2.8.1. Quantitative Outcome Measures

Outcome measures included both objective and subjective assessments of performance. Task completion time was recorded from the start of visualization to the end of the bean-transfer sequence, while error rates captured occurrences such as dropped objects, loss of target view, horizon tilt, excessive shaking, or camera repositioning. Camera stability was rated on a 0 - 5 scale by a blinded reviewer. Subjective performance was evaluated using a Likert-scale questionnaire assessing visualization clarity, depth perception, spatial orientation, perceived difficulty, and confidence with camera manipulation. This questionnaire reflected established self-assessment tools used in laparoscopic skills training.

2.8.2. Qualitative Outcome Measures

A qualitative component was incorporated to complement the quantitative findings and provide deeper insight into the cognitive processes underlying camera angulation skill acquisition. Semi-structured interviews lasting approximately 15 minutes were conducted with participants in the study group following completion of the training protocol. These interviews explored trainees' perceptions of differences between the three camera angles, the cognitive challenges associated with off-axis visualization, the adaptive strategies developed during repeated practice, and perceived progression in visuospatial understanding over time.

All interviews were audio-recorded and transcribed verbatim. The transcripts were analyzed using an inductive thematic approach [27]. Two researchers independently coded the data using an iterative process. An initial coding framework was developed based on recurring patterns and refined through discussion. Discrepancies were resolved by consensus, and final themes were generated to ensure consistency and representativeness of participant experiences. Triangulation with quantitative findings was used to enhance interpretive depth.

2.9. Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics (version 27.0; IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean \pm standard deviation (SD). Between-group comparisons were performed using independent samples *t*-tests or non-parametric equivalents where appropriate, depending on data distribution [28].

A mixed-design analysis of variance (ANOVA) was conducted to evaluate the effects of group (simulation-trained vs control) as the between-subject factor and repeated measures (session or camera angle, as applicable) as the within-subject factor. Interaction effects between group and repeated measures were also assessed [28]. Assumptions of normality and sphericity were evaluated using the Shapiro-Wilk and Mauchly's tests, respectively. Where violations of sphericity were detected, Greenhouse-Geisser corrections were applied. Post hoc comparisons were performed using Bonferroni adjustment. Missing data were minimal and handled using listwise deletion. Statistical significance was set at $p < 0.05$ [28].

Qualitative data were analyzed using Braun and Clarke's six-phase thematic analysis, allowing for inductive generation of themes. Triangulation with quantitative findings was used to enhance interpretive depth and ensure consistency across data sources [27].

2.10. Ethical Considerations

Ethical approval was obtained from the institutional review board of Zhejiang Provincial People's Hospital. Participation was voluntary, and all students provided written informed consent. Confidentiality was maintained by anonymizing videos and interview transcripts. Participants were free to withdraw at any time without academic penalty.

3. Results

A total of twenty participants were enrolled and randomized into the study group ($n = 10$) or control group ($n = 10$). Four participants (three in the study group, one in the control group) withdrew due to inconsistent attendance, leaving sixteen trainees who completed all study procedures (**Figure 1**). The final analysis included seven participants in the study group and nine in the control group. Baseline characteristics, including age, gender distribution, year of study, hand dominance, laparoscopic interest, and previous simulator exposure, showed no significant differences between groups (age: $t = -0.317$, $p = 0.756$; gender: $p = 1.000$, Fisher's exact test), confirming successful randomization, as shown in **Table 1**.

3.1. Objective Outcomes

Operation Time on 3D-Printed Model

Across five repeated assessment sessions, the study group demonstrated significantly faster operation times compared with the control group (all $p < 0.001$). Although the control group did not receive structured training, they completed the same assessment tasks at matched time intervals to enable comparison of performance trends over time.

As shown in **Figure 4**, the study group outperformed the control group from the first session onward. At the first session, the study group completed the task in 354.71 ± 46.80 s, compared with 742.50 ± 95.54 s in the control group ($F = 94.735$, $p < 0.001$). This difference remained significant across all sessions, with final session times of 281.71 ± 62.51 s in the study group and 587.50 ± 94.80 s in the control group ($F = 52.560$, $p < 0.001$).

Repeated-measures ANOVA demonstrated a significant main effect of group ($F = 81.632$, $p < 0.001$), a significant effect of session ($F = 55.851$, $p < 0.001$), and a significant group \times session interaction ($F = 8.528$, $p < 0.001$).

Simple-effects analysis showed that both groups exhibited reductions in operation time across sessions ($p < 0.05$ for all comparisons). However, the study group demonstrated a more consistent pattern of improvement, with significant reductions primarily observed between early and later sessions (1st vs 3rd, 2nd vs 3rd, 1st vs 5th, and 2nd vs 5th).

Overall, task completion time was significantly shorter in the simulation-trained group compared to the control group across all assessment sessions, as presented in **Table 2**.

Table 2. Operation time on 3D model across training sessions between groups.

	Control group	Training group	F value	p
1st session	742.50 ± 95.54	354.71 ± 46.80	94.735	<0.001
2nd session	702.50 ± 92.70^a	334.86 ± 51.93	85.937	<0.001
3rd session	656.50 ± 87.22^{ab}	282.71 ± 67.76^{ab}	83.931	<0.001
4th session	624.38 ± 92.17^{abc}	303.71 ± 51.06	66.436	<0.001

Continued

5th session	587.50 ± 94.80 ^{abcd}	281.71 ± 62.51 ^{ab}	52.560	<0.001
F value	16.560	7.767		
p	<0.001	0.004		
BSE			81.632	<0.001
WSE			55.851	<0.001
IE			8.528	<0.001

Note: a means compared with 1st session, p < 0.05; b means compared with 2nd session, p < 0.05; c means compared with 3rd session, p < 0.05; d means compared with 4th session, p < 0.05; BSE: Between-Subjects Effects; WSE: Within-Subjects Effects; IE: Interactions Effects.

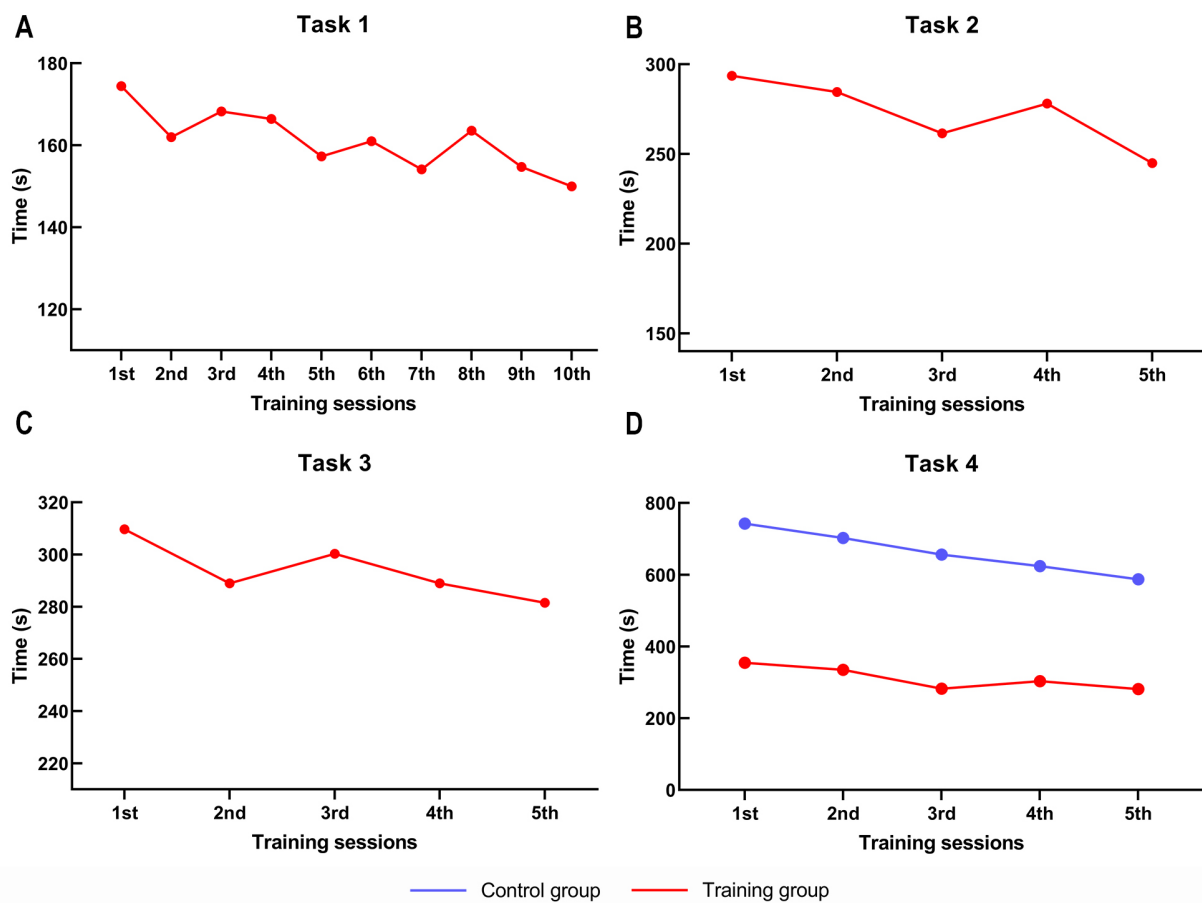


Figure 4. Learning curves for task completion time across training sessions showing mean task completion times across five repeated sessions for the simulation-trained and control groups, demonstrating progressive improvement and superior performance in the trained group.

3.2. Subjective Outcomes

Comparison between Umbilical and Non-Umbilical Angulations

Subjective evaluations from the seven study-group participants demonstrated that the umbilical angle was consistently perceived as more favorable than non-umbilical.

ical angles across several performance domains. Participants reported significantly better instrument control at the umbilical entry (median 4.0 vs. 3.0, $p = 0.017$), along with improved spatial orientation (3.0 vs. 2.0, $p = 0.038$) and more effective camera-instrument coordination (4.0 vs. 3.0, $p = 0.011$). They also found tasks easier to complete smoothly and without discomfort under the umbilical angle (5.0 vs. 3.0, $p = 0.001$), and described the learning curve as gentler and quicker to master compared with non-umbilical angles (3.0 vs. 2.0, $p = 0.007$). In contrast, no significant differences were observed between the two angle categories regarding visual clarity and depth perception ($p = 0.073$) or levels of stress and concentration ($p = 0.535$). These findings suggest that while perceptual clarity was similar across visualization angles, the umbilical view provided distinct advantages in motor control and spatial processing. Participants' self-evaluation revealed a strong preference for the umbilical camera angle over other angulations. The umbilical angle was rated significantly higher for instrument control accuracy, reduction of spatial disorientation, minimization of visual obstruction, task completion smoothness, and a gentler learning curve (**Table 3**).

Table 3. Self-Evaluation of operative performance under different camera angles.

Item	Umbilical	Other angulations	p
The instrument control was accurate under this angle.	4.0 (3.0, 5.0)	3.0 (2.0, 3.0)	0.017
The visual field was clear, and it was easy to judge depth and anatomy.	4.0 (4.0, 5.0)	4.0 (3.0, 4.0)	0.073
Spatial disorientation was unlikely to occur during the procedure under this angle.	3.0 (3.0, 4.0)	2.0 (2.0, 3.0)	0.038
Camera-instrument interference or visual obstruction was unlikely to occur under this angle.	4.0 (3.0, 4.0)	3.0 (2.0, 3.0)	0.011
I felt less stressed and was able to focus under this angle.	2.0 (1.0, 2.0)	2.0 (1.0, 2.0)	0.535
I could complete the task smoothly without major discomfort or frustration.	5.0 (4.0, 5.0)	3.0 (2.0, 3.0)	0.001
The learning curve was gentle and I could master this angle quickly.	3.0 (3.0, 4.0)	2.0 (1.0, 3.0)	0.007

3.3. Perceived Training Effectiveness and Educational Value

Participants rated instructor guidance and the training structure extremely highly, with median scores of 5.0 for skill development, spatial awareness, camera coordination, and hand-eye coordination. Willingness to undergo additional non-standard angle training also scored 5.0 (IQR 3.0 - 5.0). Participants strongly agreed that laparoscopic training curricula should incorporate tasks using varying camera angles (4.0 (3.0 - 5.0)) and that the training design has meaningful potential to enhance teaching systems (4.0 (4.0 - 5.0)). Overall, the subjective assessment indicated that participants found the training highly valuable. The guidance from instructors and the improvement in spatial and hand-eye coordination were rated highest, and most participants agreed that laparoscopic curricula should include training from different camera perspectives (**Table 4**).

Table 4. Subjective assessment of training effectiveness and educational value.

Item	Value
The guidance provided by instructors/researchers significantly contributed to my skill development.	5.0 (5.0, 5.0)
The training improved my spatial awareness, camera coordination, and hand-eye coordination.	5.0 (5.0, 5.0)
I would be willing to undergo more training under non-standard camera angles in the future.	5.0 (3.0, 5.0)
Laparoscopic curricula should systematically include tasks from different camera perspectives.	4.0 (3.0, 5.0)
The design of this training has great potential to improve laparoscopic teaching systems and equipment setup.	4.0 (4.0, 5.0)

3.4. Qualitative Outcomes

Semi-structured interviews revealed three major themes:

3.4.1. Cognitive Difficulty and Adaptation

Participants initially described off-axis views, especially Palmer's Point, as disorienting and mentally challenging. This experience aligns with findings by Aust and other researchers [29] [30], who noted that repeated exposure helps novices learn to anticipate rotational discrepancies and make better sense of spatial cues.

P5: *“The off-axis perspective forced me to think harder than usual. But the more I practiced, the quicker I adapted. Eventually, interpreting those angles felt much easier.”*

3.4.2. Importance of Repetition and Structured Practice

Repetition was consistently identified by participants as essential for developing proficiency. Although many described the early sessions as mentally taxing, they also noted a clear reduction in cognitive effort as practice progressed.

P2: *“At the beginning, it felt mentally exhausting, but after repeating the task several times, it became much easier to manage.”*

This progression aligns with the findings of Sankaranarayanan *et al.* [31], who reported that repeated training, particularly under cognitive load, enhances learners' ability to manage mental demands and improves performance in real surgical tasks. Together, these insights highlight the value of structured, repetitive practice in building both skill and cognitive resilience.

3.4.3. Angle-Specific Learning Curves and Preferences

Participants reported clear differences in how easily they adapted to each viewing angle. The umbilical angle was consistently preferred for its intuitive and ergonomically favorable orientation. In contrast, the Lee-Huang angle, though initially unfamiliar, became manageable with repeated exposure. Palmer's Point remained the most challenging due to its off-axis perspective, yet participants noted meaningful progress with structured guidance. One trainee reflected,

P1: *“With Palmer's Point, I kept losing my sense of direction at first, but once I understood the angle's logic, my confidence improved a lot.”*

These observations align with Supe *et al.* [5], who emphasized the importance of ergonomically optimized views in reducing cognitive strain and improving ef-

iciency in laparoscopic performance. The participants' experiences highlight how ergonomic principles shape angle-specific learning curves and influence preferences during skill development.

3.5. Angle-Specific Performance Outcomes

Tables 5-7 present angle-specific performance outcomes for task completion time, error rates, and camera stability across the three camera positions (umbilical, Lee-Huang, and Palmer's Point).

Table 5. Task completion time across camera angles.

Angle	Study (Mean ± SD)	Control (Mean ± SD)	p-value
Umbilical	151.14 ± 2.41	595.00 ± 9.68	<0.001
Lee-Huang	245.71 ± 3.68	665.00 ± 9.68	<0.001
Palmer	280.57 ± 3.31	735.00 ± 9.68	<0.001

Note: Values are presented as mean ± standard deviation. p-values from independent-samples t-tests comparing groups at each camera angle.

Table 6. Error rates across camera angles.

Angle	Study (Mean ± SD)	Control (Mean ± SD)	p-value
Umbilical	1.29 ± 0.49	4.33 ± 0.50	<0.001
Lee-Huang	2.00 ± 0.00	5.33 ± 0.50	<0.001
Palmer	3.00 ± 0.00	7.33 ± 0.50	<0.001

Note: Error rates represent the mean number of errors per task. Values are presented as mean ± standard deviation. p-values derived from independent samples t-tests.

Table 7. Camera stability scores across camera angles.

Angle	Study (Mean ± SD)	Control (Mean ± SD)	p-value
Umbilical	4.71 ± 0.49	2.00 ± 0.00	<0.001
Lee-Huang	4.00 ± 0.00	2.00 ± 0.00	<0.001
Palmer	3.00 ± 0.00	1.00 ± 0.00	<0.001

Note: Camera stability was assessed on a 0 - 5 scale by a blinded evaluator. Higher scores indicate better stability. Values are presented as mean ± standard deviation. p-values derived from independent samples t-tests.

The simulation-trained group demonstrated significantly superior performance compared to the control group across all camera angles (all $p < 0.001$). This included markedly faster task completion times, fewer procedural errors, and improved camera stability at each viewing position. Among the angles, the umbilical position consistently demonstrated the most efficient performance, whereas Palmer's Point represented the most challenging orientation.

For task completion time, a mixed-design ANOVA revealed a significant main

effect of group ($p < 0.001$, $\eta_p^2 = 0.999$), indicating that the simulation-trained group performed substantially faster than controls. A significant main effect of camera angle was also observed ($p < 0.001$, $\eta_p^2 = 1.000$), confirming that performance differed across the three viewing positions. Additionally, a significant interaction between group and camera angle ($p < 0.001$, $\eta_p^2 = 0.994$) indicated that the magnitude of training-related improvement varied depending on camera angulation.

Analysis of error rates similarly demonstrated a significant main effect of group ($p < 0.001$, $\eta_p^2 = 0.959$), with fewer errors observed in the simulation-trained group. A significant main effect of camera angle ($p < 0.001$, $\eta_p^2 = 0.979$) and a significant interaction effect ($p < 0.001$, $\eta_p^2 = 0.790$) were also identified, indicating that error reduction differed across the three camera positions.

Camera stability scores followed the same pattern. There was a significant main effect of group ($p < 0.001$, $\eta_p^2 = 0.992$), with higher stability achieved by the trained participants. A significant effect of camera angle ($p < 0.001$, $\eta_p^2 = 0.942$), along with a significant interaction effect ($p < 0.001$, $\eta_p^2 = 0.584$), demonstrated that improvements in stability were dependent on camera angulation. The very large effect sizes observed should be interpreted in the context of the small sample size and controlled simulation environment. Overall, these findings confirm that simulation-based training not only enhances performance across all viewing conditions but also differentially improves adaptation to specific camera angles, with the greatest benefits observed in more complex, off-axis perspectives.

3.6. Integration of Findings

Across objective metrics, subjective ratings, and qualitative feedback, structured simulation-based camera-angulation training produced clear improvements in operative performance. Trainees who received systematic practice demonstrated faster completion times, fewer errors, greater stability, and stronger visuospatial confidence than controls. Collectively, these results support the incorporation of angle-specific camera-handling modules into early laparoscopic skills curricula.

4. Discussion

Structured and standardized curricula for laparoscopic camera training remain limited, and no consensus yet exists regarding the optimal timing or method for introducing camera-angulation skills during early minimally invasive surgical (MIS) education. This randomized controlled study demonstrates that a focused, angle-specific simulation curriculum can meaningfully enhance novice performance across three clinically relevant trocar positions. Consistent with the wider simulation literature [10], our results show that repeated, deliberate exposure to multi-angle visualization produces significantly greater improvements than theory-only preparation. Baseline characteristics confirmed that the two groups were comparable before training, with no significant differences in age ($t = -0.317$, $p = 0.756$), gender ($p = 1.000$), academic year, hand dominance, laparoscopic interest, or prior simulator experience (Table 1). This comparability ensures that the sub-

sequent performance differences can be attributed directly to the intervention.

A central finding of our study is the substantial improvement in task completion time among simulation-trained participants. Across five sessions of suturing on the 3D-printed model, the training group consistently outperformed controls, beginning with a mean time of 354.71 ± 46.80 s in the first session compared with 742.50 ± 95.54 s in controls, and maintaining significantly shorter times throughout the training sequence (all $p < 0.001$). By the fifth session, trained participants averaged 281.71 ± 62.51 s, whereas controls remained more than twice as slow at 587.50 ± 94.80 s (**Table 2**). These differences were supported by mixed-ANOVA results showing highly significant between-subject effects (FBSE = 81.632, $p < 0.001$), within-subject effects (FWSE = 55.851, $p < 0.001$), and interaction effects (FIE = 8.528, $p < 0.001$), confirming that training produced a robust and sustained influence on performance. Simple effects analysis showed that the control group improved significantly between nearly all sessions (all $p < 0.05$), while the study group demonstrated more stable, progressively refined performance, with significant gains occurring only between Sessions 1 - 3, 2 - 3, 1 - 5, and 2 - 5. This pattern indicates that untrained participants were still adapting, whereas trained participants achieved more consistent visuospatial calibration earlier in the process.

Subjective evaluations further clarified the cognitive and perceptual advantages associated with the umbilical angle. Participants rated the umbilical port significantly higher than non-umbilical angles in instrument control (median 4.0 vs. 3.0, $p = 0.017$), spatial orientation (3.0 vs. 2.0, $p = 0.038$), camera-instrument coordination (4.0 vs. 3.0, $p = 0.011$), smoothness of task completion (5.0 vs. 3.0, $p = 0.001$), and perceived learning curve (3.0 vs. 2.0, $p = 0.007$). No significant differences emerged for visual clarity ($p = 0.073$) or stress levels ($p = 0.535$), suggesting that perceptual demands remained similar across angles, whereas motor-spatial demands and cognitive load were substantially reduced at the umbilical position (**Table 3**).

These findings align with the angle-specific performance outcomes, where the umbilical position consistently demonstrated superior efficiency, while Palmer's Point posed the greatest challenge due to its off-axis orientation. This pattern likely reflects increased demands on mental rotation and spatial transformation when visualizing anatomy from non-intuitive perspectives. The Lee-Huang angle, which preserves a more central visual axis, showed intermediate difficulty and a smoother adaptation trajectory. Together, these results emphasize that exposure to varied camera angles is essential for developing visuospatial flexibility, and support the integration of structured multi-angle training into early laparoscopic education.

The influence of camera angle on task difficulty was further reinforced by the qualitative data. Participants consistently described Palmer's Point as the most mentally challenging angle due to the need for increased mental rotation and interpretation of a lateralized view, a pattern that mirrors its objectively longer operation times and higher pre-training error burden [29] [30]. In contrast, the Lee-

Huang Point was experienced as moderately difficult but demonstrated a smooth and predictable learning curve, consistent with the idea that vertical shifts preserve midline symmetry and impose less spatial confusion than lateral shifts [32] [33]. These angle-dependent trends parallel the observed quantitative performance differences, confirming that visuospatial demands vary systematically with port location.

Deliberate practice emerged as a critical factor in cognitive adaptation. Participants in the study group frequently reported that repetition enabled them to transition from early disorientation to a progressively refined understanding of spatial relationships. The observed reductions in common novice errors such as horizon tilt, repeated camera repositioning, and loss of target visualization supported this perceptual learning trajectory. The qualitative descriptions and comparative trends of our study illustrate a clear divergence between groups, with the control cohort showing minimal and inconsistent improvement while trained participants exhibited a steady reduction in visuomotor mistakes.

Camera stability improved markedly in the study group as well. Although specific numeric stability values were not provided in the raw data, independent t-tests demonstrated statistically significant group differences across all angles at post-testing (all $p < 0.01$), indicating that structured training enhanced the ability to maintain a steady image and minimize unnecessary micro-movements. This improvement is clinically relevant because camera instability is a major contributor to surgeon frustration, workflow disruption, and error propagation in the operative environment [34]-[36]. Subjective assessments of educational impact were uniformly positive, with participants rating the training's contribution to spatial awareness, camera coordination, and hand-eye coordination at a perfect median score of 5.0 (Table 4). Willingness to engage in further non-standard angle training was also high (median 5.0), and participants largely agreed that systematic multi-angle exposure should be incorporated into laparoscopic curricula (median 4.0). These perceptions align with the objective findings and support the educational relevance of early camera-angulation training.

Taken together, the quantitative improvements, subjective perceptions, and qualitative insights converge to demonstrate that structured, angle-specific simulation training is highly effective in accelerating the acquisition of laparoscopic camera-handling skills. The statistical robustness of the operation-time analyses, the clear subjective preference for intuitive midline visualization, and the thematic patterns describing cognitive adaptation collectively reinforce the value of early, deliberate, and multi-angle training in MIS education. This evidence highlights the need for formal integration of dedicated camera-angulation modules into pre-clinical and early clinical surgical curricula to better prepare novices for the visuospatial complexities of real operative environments.

5. Strengths and Limitations

This study has several strengths, including a randomized controlled design that

enhances internal validity, a standardized simulation setup that ensured consistent learning conditions, and a mixed-methods approach that provided both quantitative performance data and qualitative insight into trainees' learning processes. Evaluating three different trocar angles also offered a clearer understanding of how visual perspective influences novice performance.

However, the study has limitations. The sample size was small and drawn from a single center, which may limit generalizability. The box trainer lacked anatomical realism, long-term retention of skills was not assessed, and qualitative interviews were conducted only with the intervention group. Future work should involve larger, multi-institutional samples, higher-fidelity simulators, and follow-up assessments to evaluate skill durability and real operative transferability.

6. Conclusion

Our study shows that structured, angle-specific simulation training significantly improves novices' laparoscopic camera-handling skills. Trainees who received hands-on practice demonstrated faster task completion, fewer errors, better camera stability, and greater confidence than those who received theory alone. Subjective feedback and qualitative insights further confirmed that repeated exposure across multiple angles helps learners transition from early disorientation to improved visuospatial understanding. Such findings will contribute to dedicated camera-angulation modules early in MIS education. Providing trainees with controlled, systematic exposure to different visual perspectives can strengthen foundational skills and better prepare them for the demands of real laparoscopic surgery. Camera handling should be recognized as a core competency alongside other basic laparoscopic techniques.

Availability of Data and Materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable academic request.

Author Contributions

R.J.N. conceived and designed the study, collected the data, performed the analyses, and drafted the manuscript. J.W. assisted with data analysis and interpretation. S.M.A. contributed to data collection and manuscript editing. Q.M. assisted with data collection. E.N.D. provided key input on the research framework. Z.W. supervised the study design and methodology, critically reviewed and refined the manuscript, and approved the final version for submission. All authors read and approved the final manuscript.

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Ethical Approval

This study was reviewed and approved by the Ethics Committee of Zhejiang Provincial People's Hospital (Approval No. KY2025045) on 31 March 2025. All procedures were conducted in accordance with the ethical standards of the institutional research committee and the principles outlined in the Declaration of Helsinki (1964) and its subsequent amendments.

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Informed Consent

Signed informed consent was provided for each participant before the commencement of the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest and no relevant financial or non-financial interests to disclose.

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Appendix: Questionnaire

Please select the option that best reflects your actual experience during the training. All questions use a 5-point Likert scale:

Item	Umbilical	Other angulations
Q1. The instrument control was accurate under this angle.	1 - 5	1 - 5
Q2. Spatial disorientation was unlikely to occur during the procedure under this angle.	1 - 5	1 - 5
Q3. Camera-instrument interference or visual obstruction was unlikely to occur under this angle.	1 - 5	1 - 5
Q4. The visual field was clear, and it was easy to judge depth and anatomy.	1 - 5	1 - 5
Q5. I felt less stressed and was able to focus under this angle.	1 - 5	1 - 5
Q6. I could complete the task smoothly without major discomfort or frustration.	1 - 5	1 - 5
Q7. The learning curve was gentle and I could master this angle quickly.	1 - 5	1 - 5

Note: 1 = Strongly Disagree/Very Difficult, 5 = Strongly Agree/Very Easy.

Q8: Do you believe that the guidance provided by instructors/researchers during the training significantly contributed to your skill development?

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

Q9: To what extent do you think this training improved your spatial awareness, camera coordination, and hand-eye coordination in laparoscopic procedures?

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

Q10: Would you be willing to undergo more laparoscopic training under “non-standard” camera angles in the future to enhance your surgical abilities?

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

Q11: Do you think laparoscopic training curricula should systematically incorporate tasks performed from different camera perspectives?

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

Q12: Do you think the design of this training has great potential to improve laparoscopic teaching systems and equipment setup?

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.