Article

Impact of Simulation Training Combined With Video Debriefing on Surgical Skill Acquisition and Perioperative Outcomes in Laparoscopic Adrenalectomy

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AIM: To investigate the effect of a comprehensive training model combining simulation training and video debriefing on improving the surgical skills of surgeons performing laparoscopic adrenalectomy and to evaluate its influence on perioperative outcomes in clinical practice.
METHODS: This retrospective study included nine surgeons who completed training between January 2021 and December 2024 and 182 laparoscopic adrenalectomies performed by them. All surgeons underwent both a traditional and a comprehensive training phase, combining simulation training with video debriefing. Accordingly, a total of 79 cases were completed during the traditional training phase, and 103 cases were completed during the comprehensive training phase. The theoretical knowledge scores of the surgeons, Objective Structured Assessment of Technical Skills (OSATS) scores, surgical confidence scores, and corresponding perioperative indicators (operation time, intraoperative blood loss, conversion to open surgery, and postoperative recovery indicators) were compared between the two phases.
RESULTS: Compared with the traditional training phase, the comprehensive training phase significantly improved the theoretical knowledge scores of the surgeons [43.00 (42.00, 43.00) vs. 41.00 (38.00, 43.00), $p = 0.028$] and significantly enhanced all dimensions and the total OSATS scores (all $p < 0.05$). The confidence of the surgeons in "independently performing surgery", "understanding the operation steps" and "intraoperative decision-making" was also significantly increased (all $p < 0.05$). Regarding clinical outcomes, patients treated during the comprehensive training phase had significantly shorter operation times [82.00 min vs. 107.00 min, $p < 0.001$], reduced blood loss [64.00 mL vs. 104.00 mL, $p < 0.001$], and significantly shorter times to first postoperative oral intake [13.00 h vs. 31.00 h, $p < 0.001$], ambulation [13.00 h vs. 16.00 h, $p = 0.002$], and postoperative hospital stay [4.00 days vs. 5.00 days, $p < 0.001$]. No statistically significant difference in the conversion rate to open surgery was observed between the two groups ($p = 0.816$).
CONCLUSIONS: The integrated training model combining simulation training and video debriefing effectively improves the theoretical knowledge of surgeons, technical skills, and surgical confidence in laparoscopic adrenalectomy. Notably, these educational improvements were associated with measurable enhancements in real-world surgical performance and improved perioperative patient outcomes. This model represents an efficient surgical training strategy with significant clinical translational value.

Keywords: simulation training; video debriefing; laparoscopic surgery; adrenalectomy; skills assessment

Introduction

Adrenal tumors are among the most common diseases of the endocrine system. Their overall prevalence has increased significantly with the widespread use of imaging technology. The incidence of adrenal tumors in adults ranges from 0.2% to 3.2%, and it increases markedly with age [1]. There are diverse types of adrenal tumors, including adrenal adenoma, primary aldosteronism, cortisol-secreting adenoma, pheochromocytoma, and the relatively rare adrenal carcinoma [2,3]. Consequently, the diagnosis and management of adrenal tumors have become major clinical concerns, as treatment strategies directly influence long-term patient outcomes and quality of life. Among treatment approaches for adrenal tumors, laparoscopic adrenalectomy (LA) is currently regarded as the standard surgical method for treating most benign adrenal tumors [4,5]. Compared with traditional open surgery, laparoscopic surgery offers significant advantages, including less surgical trauma, faster postoperative recovery, reduced pain, and shorter hospital stay; therefore, it is widely used in clinical practice [6–8]. However, the adrenal gland is located adjacent to key anatomical structures such as the inferior vena cava, renal vein, and crus of the diaphragm, and different tumor types (such as pheochromocytoma) can markedly affect hemodynamics during surgery, making adrenal surgery one of the more technically challenging laparoscopic procedures [9–11]. The surgical procedure requires meticulous dissection and flexible exposure of blood vessels within a narrow

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operative space, as well as rapid responses to unexpected events under complex conditions [12]. Therefore, although laparoscopic techniques have been widely adopted in urology, adrenal surgery still presents a significant "learning curve", requiring a high level of surgical experience and technical skills from the surgeon [10].

However, the traditional apprentice-style "learning in the operating room" is often insufficient for mastering the advanced skills required for LA, due to inherent challenges such as a lack of tactile feedback, limited depth perception within a two-dimensional field, and high demands on hand-eye coordination [13,14]. This situation underscores the need for more standardized and effective training paradigms.

Simulation-based training has therefore emerged as an important tool, providing a safe, repeatable environment for practicing and assessing core laparoscopic skills [15]. At the same time, with advances in surgical video recording and digital technologies, video-based debriefing, as a structured feedback approach, has demonstrated clear advantages in surgical education [16]. Video debriefing allows learners to review their own operative procedures from a third-person perspective, helping them identify blind spots, redundant paths, and non-standard operations, thereby strengthening self-reflection ability and improving precision in laparoscopic surgery [17]. Although simulation training and video debriefing have made significant progress in basic laparoscopic skills training, evidence for complex laparoscopic procedures (such as adrenalectomy) remains relatively limited. Current research largely focuses on educational indicators, including improved skill scores and reduced operating time, but lacks real-world evidence linking training effectiveness to patient perioperative outcomes. For moderately complex laparoscopic procedures such as adrenal gland surgery, whether training quality affects patient safety, intraoperative bleeding, and operative time remains insufficiently investigated. Furthermore, the optimal frequency of simulation training, the feedback structure of video debriefings, and the contribution of different training components to operative skill development remain unclear. Therefore, more focused studies are needed to evaluate the practical effects of comprehensive training models in laparoscopic adrenal gland surgery.

In this context, the present study aimed to retrospectively compare young surgeons trained using a combination of simulation training and video debriefing with those receiving routine training. By comparing their operative performance during laparoscopic adrenal surgery (LAS) and perioperative patient indicators, this study explored whether the comprehensive training system provides practical clinical advantages. The primary innovation of this study lies in the integrated application of two established, yet often separately investigated, educational strategies, simulation training and structured video debriefing, within a cohesive curriculum for a complex procedure. Furthermore, it moves beyond the assessment of educational metrics alone by evaluating the translation of training effects into measurable, real-world clinical outcomes for patients. This dual focus on a combined pedagogical approach and clinical endpoint validation aims to address a significant gap in the literature and provide evidence for the practical value of comprehensive training models. Additionally, this study focused on minimally invasive surgery of the adrenal gland, a unique endocrine organ, thereby contributing to the evidence framework for laparoscopic skills training in specialty surgery.

Methods

Research Design and Participants

This retrospective study included 182 patients who underwent consecutive laparoscopic adrenalectomy (LA) between January 2021 and December 2024. The researchers reviewed the training records and skills assessment files of the surgeons and categorized them into two predefined training phases. All nine surgeons completed a conventional training program by June 2022. Subsequently, in July 2022, they participated in a comprehensive training program that incorporated simulation-based training and structured video debriefings. Completion of the program was defined as achieving a predetermined proficiency score on the simulator module and attending at least two formal video debriefing sessions. Notably, no clinical surgeries were performed during the comprehensive training period. Surgeries performed between January 2021 and June 2022 were categorized as the conventional training phase, while surgeries performed between August 2022 and December 2024 occurred after completion of the comprehensive training program and were therefore categorized as the comprehensive training phase.

Following common surgical education research designs, to minimize bias resulting from differences in surgeon skill levels, this study adopted a pre-post control design with the same group of surgeons. All surgeons first completed traditional laparoscopic training and independently performed a number of LA procedures during this stage, followed by comprehensive training (simulation training combined with video debriefing), after which they continued performing LA procedures. Based on the timing of the surgery, patients were divided into a traditional training phase group and a comprehensive training phase group to compare the impact of the two training models on surgeon skill improvement and perioperative outcomes. Given that this study employs a time-series observational design, the results primarily reflect changes in associations across different training phases, rather than strictly causal relationships. This study was approved by the Ethics Committee of Peking Union Medical College Hospital (approval number: 1-25PG3085), and all procedures for data collection and analysis complied with the principles of the Declaration of Helsinki.

Nine surgeons were included in this study, comprising resident physicians, standardized training physicians, and attending physicians. Although the sample size of nine surgeons was relatively small, it was comparable to numerous previous single-center studies on simulation-based surgical training, where logistical constraints often limit the number of trainees participating in a structured curriculum. The inclusion criteria for surgeons were as follows: (1) completion of systematic laparoscopic basic skills training at the hospital, including laparoscopic instrument manipulation, basic suturing and knot-tying training, and passing the relevant competency assessments; (2) completion of continuous rotations in the urology department for at least 12 months and participation in routine diagnosis and management of adrenal tumors; (3) independent performance of laparoscopic adrenalectomy during the study period; and (4) availability of complete and analyzable training records and surgical video data. The inclusion of surgeons at different training levels (residents, standardized training physicians, and attending physicians) was intentional, as the study aimed to evaluate the effectiveness of the training model across a spectrum of surgical experience typical of a teaching hospital environment. To ensure clarity regarding surgical autonomy and role definition, all included surgeons served as the primary operating surgeon for the LA procedures analyzed. All surgeons completed two sequential phases: the "traditional training phase" and the "comprehensive training phase", performing a defined number of LA surgeries during each phase. This design aligns with many international studies evaluating laparoscopic skills training and helps reduce confounding factors arising from inter-individual differences in surgical abilities.

A total of 182 patients who underwent LA surgery were included in the analysis. The inclusion criteria were: (1) age $\geq$18 years; (2) confirmed diagnosis of benign or functional adrenal tumors based on preoperative imaging and clinical evaluation; (3) planned laparoscopic adrenalectomy via the lumbar approach; and (4) complete medical records available for analysis. The exclusion criteria were: (1) tumor diameter greater than 4 cm or strong suspicion of malignant adrenocortical carcinoma; (2) presence of other malignant tumors or severe systemic diseases; (3) patients who directly underwent open surgery due to anatomical considerations or surgeon judgment; and (4) patients with missing key perioperative data. Finally, all surgeries were classified into the traditional training surgery group and the comprehensive training surgery group based on the timing of implementation and the training stage of the surgeon at that time, allowing comparative analysis of patient perioperative outcomes.

Training Content

During the study, surgeons received two forms of training: traditional laparoscopic basic training and comprehensive training (simulation training combined with video review). Traditional training was organized uniformly by the skills training center of the hospital and focused on ensuring that surgeons mastered the fundamental skills required for laparoscopic surgery. The training content included understanding the structure and operating procedures of laparoscopic instruments, basic laparoscopic suturing and knotting techniques, hand-eye coordination training, standardized procedures for establishing and closing pneumoperitoneum, principles of trocar site design and instrument placement, basic hemostasis procedures, and the initial use of energy devices. This stage emphasized general skills applicable to most laparoscopic procedures, while the specific technical challenges and related knowledge required for adrenal gland surgery were addressed to a relatively limited extent.

Building on traditional training, the comprehensive training further enhanced the mastery of surgeons for specific skills in adrenalectomy and consisted of two components: simulation training and structured video debriefing. The simulation training utilized a highly realistic anatomical model to create a safe, repeatable platform for technical skill development. Within this platform, the training focused on three core dimensions. First, emphasis was placed on refining advanced laparoscopic techniques, including precise tissue dissection within confined spaces, accurate activation and power control of energy platforms, such as ultrasonic scalpels, and proactive hemostasis of fragile small blood vessels surrounding the adrenal glands (e.g., branches of the adrenal artery). Second, the training employed a highly realistic anatomical module in the simulator to facilitate identification and spatial understanding of key anatomical structures in the adrenal region. Trainees repeatedly practiced identifying the adrenal veins and their confluence with the renal veins and the inferior vena cava within complex adipose tissue, and clearly recognizing the spatial orientation of adjacent structures, such as the diaphragmatic crura, pancreas, and upper poles of the kidneys, thereby establishing a precise anatomical mental map.

The structured video debriefing was led by an experienced senior physician. During these sessions, trainees carefully reviewed their surgical recordings. The debriefing process extended beyond simple viewing and represented a structured, interactive, analytical exercise. The instructor guided the trainee through a step-by-step review and annotation of key surgical steps. Both parties jointly evaluated surgical field stability and the efficiency and smoothness of instrument movements, identified unnecessary instrument trajectories, inefficient movements, or inappropriate visual field selection, and analyzed potential risks and critical intraoperative decision points. Through freeze-frame analysis of surgical videos, the instructor helped trainees translate abstract errors into specific, actionable corrective strategies, leading to targeted improvements in subsequent simulation exercises or clinical procedures.

Evaluation Indicators for Physician Training Effectiveness

All participating surgeons underwent systematic assessments during both the traditional and comprehensive training phases. The assessments included theoretical knowledge tests, surgical skills assessments using the Objective Structured Assessment of Technical Skills (OSATS), and surgical confidence questionnaires.

The theoretical knowledge test was conducted as a closed-book examination. The test consisted of multiple-choice and true/false questions designed to assess the understanding of adrenal gland anatomy by the participants, vascular variations, key procedural steps in laparoscopic adrenalectomy, and the management of potential complications. The examination had a maximum score of 50 points, with higher scores indicating a more comprehensive theoretical understanding.

The OSATS scale was used to evaluate the operative surgical skills of a surgeon. OSATS is a structured technical assessment tool commonly used in international surgical education and allows comprehensive evaluation of operative performance in real or simulated surgical settings across multiple dimensions [18]. In this study, OSATS scores were derived from three laparoscopic adrenalectomy surgical videos recently completed by each surgeon after training. The videos were evaluated independently and in a blinded manner by two senior surgeons, and the average score across the three assessments was calculated. The scoring criteria included seven dimensions: tissue handling (organizational processing), time and motion efficiency, instrument manipulation, medical device cognition, assistant coordination and mobilization, mastery of the surgical procedure, and overall understanding of the surgical workflow. Each dimension was scored using a 1–5 Likert scale, with higher scores indicating greater technical proficiency.

Finally, each surgeon completed a surgical confidence questionnaire using a 1–5 Likert scale. The questionnaire assessed four specific domains: confidence in independently performing the surgery (‘independent surgical performance’), ability to identify key anatomical structures (‘anatomical structure recognition’), understanding of surgical steps and operational capability (‘procedural understanding and operative ability’), and confidence in intraoperative decision-making (‘intraoperative decision-making ability’). Higher scores indicated greater levels of self-reported surgical confidence.

Perioperative Assessment of Patients

Assessment of Population Baseline Data

Baseline demographic and clinical characteristics of the included patients were collected, including age, gender, body mass index (BMI), tumor location, education level, tumor diameter, and tumor type. These variables were recorded to ensure comparability of baseline characteristics between the two patient groups.

Perioperative Observation Indicators

Perioperative indicators for patients included both intraoperative and postoperative variables. Intraoperative indicators comprised operation duration, intraoperative blood loss, and the conversion rate to open surgery. Postoperative indicators included time to first oral intake, time to first ambulation, and the length of postoperative hospital stay.

Statistical Analysis

All data in this study were analyzed using SPSS (version 26.0, IBM Corp., Armonk, NY, USA). For surgeon-related variables, normality was assessed using the Shapiro–Wilk test. Normally distributed data are presented as mean $\pm$ SD and an appropriate statistical test method is selected based on whether the data are paired or independent. Non-normally distributed data are presented as median (interquartile range, IQR) and were compared using the Wilcoxon signed-rank test. Likert scores (ordinal data) were also analyzed using the Wilcoxon signed-rank test.

For patient-related continuous variables, normality was evaluated using the Shapiro–Wilk test. Normally distributed data were compared using the independent-samples *t*-test, with results reported as the mean difference and its 95% confidence interval. Non-normally distributed variables were analyzed using the Mann–Whitney *U* test, with the Hodges–Lehmann estimator used to report the median difference and 95% CI. Categorical variables are presented as frequencies and percentages and were compared using the chi-square (χ^2) test. For 2 $\times$ 2 contingency tables, the odds ratio (OR) with a 95% confidence interval (CI) was calculated using cross-tabulation analysis. For larger contingency tables, Cramér’s V was reported as a measure of effect size. All statistical tests were two-tailed, and $p < 0.05$ was considered statistically significant.

Results

Assessment of the Practitioner’s Knowledge Level and Skills

As shown in Table 1, the median theoretical knowledge score of the physicians increased from 41.00 to 43.00 after comprehensive training, representing a statistically significant difference (p = 0.028). This finding suggests that the comprehensive training model, combining simulation training and video review, was associated with improved mastery of the theoretical principles of laparoscopic adrenalectomy. Analysis of the seven dimensions of the OSATS scores demonstrated that physicians’ technical skill scores across all dimensions were significantly higher after comprehensive training than in the traditional training phase (all $p < 0.05$). These dimensions included tissue handling (organizational processing), instrument operation, medical device cognition, assistant collaboration and mobilization, time-based motion efficiency, mastery of the surgical procedure, and understanding of the surgical workflow (Table 1).

Table 1. Assessment of physicians' knowledge and technical skills.

Variables	Traditional training (n = 9)	Comprehensive training (n = 9)	Statistic	*p*-value
Knowledge score	41.00 (38.00, 43.00)	43.00 (42.00, 43.00)	Z = –2.20	0.028
Tissue handling (organizational processing)	3.33 (3.33, 4.00)	4.33 (4.33, 4.67)	Z = –2.68	0.007
Instrument operation	3.67 (3.67, 4.00)	4.33 (4.33, 4.67)	Z = –2.15	0.024
Medical device cognition	3.67 (3.33, 3.67)	4.33 (4.33, 4.67)	Z = –2.54	0.011
Assistant collaboration and mobilization	3.67 (3.67, 4.00)	4.33 (4.33, 4.33)	Z = –2.67	0.007
Time and motion efficiency	3.67 (3.67, 4.00)	4.33 (4.33, 4.33)	Z = –2.06	0.040
Mastery of the surgical procedure	3.67 (3.67, 4.00)	4.33 (4.00, 4.33)	Z = –2.53	0.011
Understanding of surgical workflow	3.67 (3.67, 4.33)	4.33 (4.33, 4.67)	Z = –2.68	0.007
Total score	26.00 (25.33, 26.67)	30.33 (29.33, 31.00)	Z = –2.68	0.007

Table 2. Confidence level of surgeons in laparoscopic adrenalectomy.

Variables	Traditional training (n = 9)	Comprehensive training (n = 9)	Statistic	*p*-value
Independent surgical performance	4.00 (3.00, 4.00)	4.00 (4.00, 5.00)	Z = –2.33	0.020
Anatomical structure recognition	4.00 (3.00, 4.00)	4.00 (4.00, 4.00)	Z = –1.89	0.059
Procedural understanding and operative ability	4.00 (3.00, 4.00)	5.00 (4.00, 5.00)	Z = –2.27	0.023
Intraoperative decision-making ability	3.00 (3.00, 4.00)	5.00 (4.00, 5.00)	Z = –2.26	0.024

Furthermore, the total OSATS score during the comprehensive training phase was significantly higher than that observed in the traditional training phase. These results indicate that the laparoscopic surgical skills of the trainees were rated significantly higher following implementation of the comprehensive training model.

Surgical Confidence Assessment

As shown in Table 2, regarding surgical confidence, physicians' confidence scores for "independent surgical performance", "procedural understanding and operational ability", and "intraoperative decision-making ability" were significantly higher after comprehensive training compared with the traditional training phase (all $p < 0.05$). Although confidence scores for "anatomical structure recognition" improved after comprehensive training, the difference did not reach statistical significance ($p = 0.059$).

Patient Baseline Data Analysis

This study analyzed data from 182 patients who underwent laparoscopic adrenalectomy performed by the participating surgeons, including 79 patients in the traditional training phase and 103 patients in the comprehensive training phase. There were no statistically significant differences between the two groups in baseline characteristics, including age, BMI, tumor diameter, sex, tumor location, tumor type, and education level (all $p > 0.05$). These findings indicate good baseline comparability between the two groups (Table 3).

Perioperative Observation Indicators

Analysis of perioperative indicators revealed differences in several key metrics between the two phases (Table 4). The median operation time was shorter during the comprehensive training phase, and the median intraoperative blood loss was significantly reduced ($p < 0.001$). There was no statistically significant difference between the two groups in the proportion of patients who required conversion to open surgery ($p = 0.816$). Additionally, patients in the comprehensive training phase experienced significantly earlier time to first oral intake, earlier time to ambulation, and shorter postoperative hospital stay ($p < 0.05$).

Discussion

This retrospective study systematically evaluated the effectiveness of simulation training combined with video debriefing in the training of surgeons performing laparoscopic adrenalectomy (LA). The results suggest an association between this comprehensive training model and improvements in surgeons' laparoscopic skills, as well as better perioperative outcomes, including reduced intraoperative bleeding, shorter operation time, and faster postoperative recovery. These findings support the potential value of this comprehensive training model as an approach that may improve the quality of laparoscopic adrenalectomy and demonstrate clear application value in training for technically demanding laparoscopic procedures.

The study confirmed through scale-based assessment that simulation training combined with video debriefing is associated with improvements in surgical skills across multiple dimensions. After comprehensive training, surgeons' OSATS scores across all seven domains, as well as the total score, showed significant improvement, which is consistent with findings from numerous domestic and international surgical education studies [19–21]. Simulation training provides a safe, controllable, and repeatable practice environment, enabling surgeons to perform technically challenging skill training without patient risk. In adrenal surgery, exposure and management of adjacent large blood vessels (such as the inferior vena cava and renal veins) and other critical anatomical structures require high precision

Table 3. Comparison of baseline characteristics between the two groups of patients.

Variables	Traditional training (n = 79)	Comprehensive training (n = 103)	Effect size	Statistic	*p*-value
Age (years)	58.86 ± 7.05	59.47 ± 8.50	Mean difference (95% CI): –0.61 (–2.88, 1.67)	t = –0.51	0.609
BMI (kg/m^2)	25.54 ± 3.04	26.19 ± 2.07	Mean difference (95% CI): –0.65 (–1.44, 0.14)	t = –1.63	0.106
Tumor diameter (cm)	2.00 (1.50, 2.55)	1.90 (1.60, 2.90)	Median difference (Hodges–Lehmann estimate, 95% CI): 0.00 (–0.30, 0.20)	Z = –0.09	0.926
Tumor diameter grouping, n (%)			OR (95% CI): 1.06 (0.59, 1.91)	χ^2 = 0.04	0.841
>2 cm	38 (48.10)	48 (46.60)			
≤2 cm	41 (51.90)	55 (53.40)			
Gender, n (%)			OR (95% CI): 0.91 (0.51, 1.64)	χ^2 = 0.10	0.758
Female	35 (44.30)	48 (46.60)			
Male	44 (55.70)	55 (53.40)			
Tumor location, n (%)			OR (95% CI): 1.09 (0.61, 1.95)	χ^2 = 0.08	0.780
Left adrenal gland	40 (50.63)	50 (48.54)			
Right adrenal gland	39 (49.37)	53 (51.46)			
Tumor type, n (%)			OR (95% CI): 0.59 (0.29, 1.18)	χ^2 = 2.26	0.132
Primary	57 (72.15)	84 (81.55)			
Secondary	22 (27.85)	19 (18.45)			
Education level, n (%)			Cramér’s V: 0.062	χ^2 = 0.70	0.874
Primary school	31 (39.24)	40 (38.83)			
Junior high school	30 (37.97)	41 (39.81)			
High school	11 (13.92)	16 (15.53)			
University or above	7 (8.86)	6 (5.83)			

BMI, body mass index; OR, odds ratio.

and stability. The simulation platform allows surgeons to repeatedly practice advanced techniques such as anatomical pathway identification, manipulation within confined spaces, and the application of energy devices, which may contribute to shortening the learning curve [10,21].

On the other hand, video debriefing, through a structured and reflective review process, allows surgeons to examine their surgical performance from a third-person perspective, identify error patterns and unreasonable actions, and enhance their awareness of key steps and potential risk points [22]. The results of the study by Elessawy *et al.* [23] suggest that video debriefing can enhance surgeons’ situational awareness, surgical strategy planning ability, and procedural consistency, which is highly consistent with the findings of the present study.

A central contribution of this study is the use of clinical outcomes to evaluate the training model. Surgeries performed after comprehensive training were associated with improved perioperative metrics, including reduced blood loss, shorter operative times, and faster postoperative recovery, which are consistent with greater procedural safety and efficiency. Table 4 presents the magnitude of these differences, the potential clinical implications of which are noteworthy. For example, a reduction in median blood loss may be associated with a clearer surgical field, potentially reducing the need for transfusion and improving visualization during key anatomical dissection. Shorter operative times are consistent with improved technical fluency and may also contribute to reduced anesthesia exposure and more efficient utilization of operating room resources. Furthermore, a one-day reduction in median postoperative hospital stay may have important implications for patient recovery, healthcare costs, and hospital bed turnover. The consistency of these improvements across multiple efficiency and recovery indicators supports the potential that the training outcomes are associated with enhancements in patient care. LA requires advanced proficiency in instrument control, tissue dissection, and spatial reasoning. The improvements observed in these domains during training may be associated with reduced unnecessary tissue trauma

Table 4. Comparison of perioperative outcomes between the two groups of patients.

Variables	Traditional training (n = 79)	Comprehensive training (n = 103)	Effect size	Statistic	*p*-value
Operation time (min)	107.00 (90.50, 131.00)	82.00 (69.50, 101.50)	Median difference (Hodges–Lehmann estimate, 95% CI): 27.00 (20.00, 33.00)	Z = –6.76	<0.001
Intraoperative blood loss (mL)	104.00 (83.00, 113.00)	64.00 (57.00, 71.00)	Median difference (Hodges–Lehmann estimate, 95% CI): 37.00 (31.00, 42.00)	Z = –10.80	<0.001
Time to first oral intake (h)	31.00 (26.00, 36.00)	13.00 (9.00, 20.00)	Median difference (Hodges–Lehmann estimate, 95% CI): 17.00 (15.00, 19.00)	Z = –10.91	<0.001
Time to first ambulation (h)	16.00 (12.00, 19.00)	13.00 (9.00, 18.00)	Median difference (Hodges–Lehmann estimate, 95% CI): 3.00 (1.00, 4.00)	Z = –3.03	0.002
Postoperative hospital stay (days)	5.00 (4.00, 7.00)	4.00 (2.00, 5.00)	Median difference (Hodges–Lehmann estimate, 95% CI): 2.00 (1.00, 2.00)	Z = –6.35	<0.001
Conversion to open surgery, n (%)	2 (2.53)	1 (0.97)	OR (95% CI): 0.38 (0.03, 4.24)	χ^2 = 0.05	0.816

The median difference is calculated by subtracting the comprehensive training values from the traditional training values.

and intraoperative bleeding risk. Furthermore, more standardized and efficient intraoperative procedures may yield tangible postoperative benefits, such as earlier mobilization and shorter hospital stays. Although comprehensive training was associated with improvements across several key indicators, the rate of conversion to open surgery did not differ significantly between groups. This finding suggests the primary value of the training model may lie in optimizing procedural efficiency and technical fluency within standard laparoscopic approaches, rather than substantially altering intraoperative decision-making in complex or high-risk situations. Because conversion to open surgery is influenced by multiple factors, including tumor complexity and surgeon judgment, larger studies may be required to more definitively evaluate the impact of training on this outcome.

Notably, this study also demonstrates that comprehensive training is associated with a significant improvement in surgeon confidence. In particular, in areas such as "independently performing LA surgery", "identifying key anatomical structures", and "developing intraoperative strategies", surgeons' subjective confidence scores increased significantly. The surgical training literature indicates that confidence represents an important psychological factor influencing surgical performance and is associated with operative fluency, error rates, and decision-making speed. Insufficient confidence may lead to hesitation during procedures and delayed error correction, while overconfidence may increase procedural risk. Therefore, moderate and competency-based growth in confidence may reflect improved integration of knowledge and technical skills by the surgeon, which is more conducive to stable operative performance and reasonable judgment in complex laparoscopic scenarios [24]. The confidence assessment results suggest that comprehensive training helps surgeons develop a stronger sense of competence and procedural security, which may represent an important complementary mechanism underlying improvements in technical skills.

Nevertheless, several limitations of this study should be acknowledged. First, the single-center, retrospective, pre-post design allows for causal inference but may not fully account for temporal effects or the natural progression of surgical skill acquisition. Second, while the inclusion of nine surgeons is typical for resource-intensive simulation studies and aligns with sample sizes reported in similar educational research [25,26], the limited sample size may reduce statistical power and restrict the generalizability of the findings. Third, the present analysis relied primarily on univariate comparisons. Although patient baseline characteristics were comparable between groups (Table 3), unmeasured or residual confounding factors may still influence the observed outcomes. While all procedures were performed at the same institution, potential temporal changes in perioperative management cannot be completely excluded. These factors include case-specific variables (e.g., subtle differences in tumor complexity beyond size or type and anatomical variations), surgeon-related characteristics (e.g., baseline experience and technical aptitude), and evolving perioperative management protocols, such as enhanced recovery after surgery (ERAS) implementation. The latter consideration is particularly relevant when interpreting the marked reduction in time to first oral intake, as improvements in supportive perioperative care may have interacted with enhanced surgical performance. Furthermore, subtle patient-related factors, including comorbidities or differences in pain tolerance, which were not fully captured in the present comparisons, may have influenced postoperative recovery indicators. Multivariate adjustment for these potential confounders was not feasible due to the limited sample size of surgeons and the nested structure of the data. Thus, although the observed associations are encouraging, they should be interpreted with caution in light of possible residual confounding. Finally, the lack of long-term follow-up precludes assessment of the durability of the acquired skills and the long-term retention of training effects.

In summary, the key contribution of this work is twofold. First, it explores the potential synergistic value of systematically integrating simulation training with structured video debriefing, a pedagogical combination that has not yet been extensively documented for complex laparoscopic adrenalectomy. Second, it provides evidence suggesting that the benefits of this integrated training approach are associated not only with improvements in technical skill scores and surgeon confidence but also with measurable enhancements in perioperative patient care, including reduced intraoperative bleeding, shorter operative times, and accelerated postoperative recovery. This emphasis on evaluating clinical outcomes alongside educational indicators distinguishes the present findings from studies that are limited to educational or simulated training environments. Overall, this model demonstrates potential advantages in improving skill mastery, facilitating the translation of acquired skills into clinical practice, and supporting improvements in patient safety. Future studies should include multicenter, prospective, randomized controlled trials and incorporate emerging technologies such as digital surgical performance analysis and AI-based automated scoring systems to generate stronger evidence supporting the application of comprehensive training models in advanced laparoscopic skills development.

Conclusions

This study demonstrates that simulation training combined with video debriefing is associated with significant improvements in surgeons' theoretical knowledge, operative skills, and surgical confidence during laparoscopic adrenalectomy. A key innovation of this approach is the synergistic integration of these two training modalities, which together address both the psychomotor and cognitive-reflective domains of surgical skill acquisition. These improvements are associated with measurable enhancements in surgical efficiency, including reduced intraoperative bleeding, shorter operative time, and accelerated postoperative recovery, within a real clinical setting.

This comprehensive training model appears to support improvements in the overall capabilities of surgeons and may contribute to enhanced safety and quality in laparoscopic adrenalectomy. By systematically combining deliberate practice in a risk-free simulated environment with structured visual feedback on operative performance, this model offers a pedagogical advantage over traditional or single-modality training approaches. Given its potential benefits in both skill development and clinical translation, simulation training combined with video debriefing may represent a promising strategy for incorporation into training programs for surgical residents and junior physicians, providing a systematic, reproducible, and efficient educational framework for advanced laparoscopic skills training.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

YZZ and YZ designed the research study. XCW and YZZ performed the research. YZ analyzed the data. XCW drafted this article. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee of Peking Union Medical College Hospital (approval number: 1-25PG3085), and all procedures complied with the principles of the Declaration of Helsinki. All patient information has been anonymized, making it impossible to trace back to specific individuals, thus effectively protecting patient privacy. The Ethics Committee of Peking Union Medical College Hospital waived informed consent.

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Conflict of Interest

The authors declare no conflict of interest.

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