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The Role of Simulation-Based Training in Laparoscopic Surgery

Batirov D. Y., Rakhimov A. P., Rojobov R. R., Allaberganov F. M., Yakubov Ya. B., Rustamov M. A.

Urgench State Medical Institute, Urgench, Uzbekistan

Abstract This study is devoted to evaluating the effectiveness of simulation-based training in the formation of practical skills in laparoscopic surgery. The training process was conducted step by step. At the first stage, basic skills were developed using the iModels box trainer. At the second stage, objective assessment was carried out using the Laparo Analytic simulator, followed by the third stage in which five types of operations were simulated on the LAPARO APEX simulator (laparoscopic cholecystectomy, laparoscopic appendectomy, laparoscopic hernioplasty (TAPP), laparoscopic fundoplication, and sleeve gastrectomy). During the study, a total of 265 trainees underwent comprehensive practical training, starting from general laparoscopic concepts and continuing with complex practical sessions using the Analytic module and the LAPARO APEX simulator. The trainees were divided into three groups according to their level of preparation. The results obtained showed that simulation-based training led to a reliable improvement in laparoscopic skills in all groups. The step-by-step training model demonstrated particularly high effectiveness in improving time efficiency and technical accuracy among inexperienced trainees.

Keywords Laparoscopic simulation, Simulation-based training, LAPARO APEX, Laparoscopic skills, Step-by-step education, Analytic trainer, Medical education

1. Introduction

In recent years, minimally invasive surgery, particularly laparoscopic operations, has been widely applied in clinical practice, gaining importance due to reduced trauma, shorter rehabilitation periods, and a decrease in complications for patients. However, successful performance of laparoscopic surgical techniques requires surgeons to possess a high level of psychomotor skills, visual-motor coordination, and spatial thinking abilities [1,2]. The traditional "mentor–trainee" model of skill acquisition presents several challenges related to patient safety, limited operating time, and the risk of errors [3]. In this regard, simulation-based training technologies are considered an integral component of modern surgical education [4]. Systematic reviews and meta-analyses conducted over the past five years have shown that simulation-based laparoscopic training significantly improves practical skills, reduces operative time, and decreases intraoperative errors [5–7]. Simulation training is particularly effective for residents and surgeons with limited experience [8]. The use of virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) elements in modern simulation training systems further enhances educational effectiveness [9–11]. However, due to the high cost of advanced simulators, dry-lab-based laparoscopic simulators remain the most accessible and effective solution for many training centers [12–14]. From this perspective, analyzing local experience in laparoscopic simulation training, scientifically substantiating its effectiveness, and comparing it with international literature is of great scientific and practical significance. This article presents our experience in implementing laparoscopic simulation training and evaluates its role in clinical education.

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Purpose of the Study

The main purpose of this study is to evaluate the effectiveness of a step-by-step simulation-based training model in forming practical skills in laparoscopic surgery and to scientifically substantiate the feasibility of applying this model in the educational process.

Objectives of the Study

To achieve the study goal, the following objectives were defined:

1. To analyze the theoretical and practical aspects of laparoscopic simulation-based training;
2. To evaluate the possibilities of forming initial practical skills using the iModels box trainer;
3. To objectively assess movement accuracy, time efficiency, and the number of errors using the LAPARO Analytic trainer;
4. To develop advanced skills through complex laparoscopic exercises using the LAPARO APEX simulator;
5. To compare training outcomes among groups with

different levels of preparation;
6. To determine the dynamics of skill development across simulation training stages;
7. To statistically substantiate the effectiveness of simulation-based training based on the obtained results;
8. To develop practical recommendations for improving laparoscopic education.

2. Materials and Methods

This study was conducted at the Urgench State Medical Institute within the framework of the implementation of the Driver Innovation Project entitled "Improving the effectiveness of developing high-tech surgical practice skills among surgeons of the Lower Aral Sea region," approved by Resolution No. 307 of the President of the Republic of Uzbekistan dated July 6, 2022, Appendix 7a, Clause 109. The study was carried out in a training-simulation center during 2024–2025.

The study had a prospective, interventional, and observational design and was aimed at evaluating the effectiveness of a step-by-step simulation-based training model in forming practical skills in laparoscopic surgery. The training process was organized through the sequential use of the iModels box trainer, LAPARO Analytic, and LAPARO APEX simulators.

During the study, a total of 265 trainees participated in simulation-based training courses. The trainees had medical education and varying levels of experience in laparoscopic surgery. Their ages ranged from 23 to 45 years, with a mean age of 31.8 ± 4.6 years. Gender distribution included 62% males and 38% females. Overall medical work experience ranged from 1 to 15 years. According to laparoscopic experience, trainees were divided into three groups: Group I – trainees without laparoscopic experience (n = 112, experience 1–3 years); Group II – trainees who had participated as assistants in laparoscopic operations but had limited independent practice (n = 93, experience 3–7 years); Group III – trainees with minimal independent laparoscopic experience (n = 60, experience 5–15 years).

The step-by-step training model included the following stages: At the first stage, trainees developed skills in handling laparoscopic instruments, hand-eye coordination, and movement in a two-dimensional visualization environment. At the second stage, standardized exercises using the LAPARO Analytic trainer provided objective assessment of movement accuracy, execution time, and error count. At the third stage, the LAPARO APEX simulator was used to simulate complex laparoscopic procedures in conditions close to real clinical practice, including five types of operations: laparoscopic cholecystectomy, laparoscopic appendectomy, laparoscopic hernioplasty (TAPP), laparoscopic fundoplication, and sleeve gastrectomy.

Trainee performance was evaluated based on task completion time, number of technical errors, instrument movement trajectory, and an integral score calculated by the simulator.

The obtained data were statistically processed. Results were expressed as mean values and standard deviation (Mean ± SD). Differences between groups were assessed using Student's t-test and one-way analysis of variance (ANOVA). Statistical significance was set at $p < 0.05$.

3. Results

Application of the step-by-step simulation-based training model resulted in statistically significant improvement of laparoscopic skills across all trainee groups. In Group I (inexperienced, n = 112), average task completion time decreased by 38.6% ($p < 0.001$), and the number of technical errors decreased by 42.1% by the end of training. The overall integral score increased significantly compared to baseline. In Group II (n = 93), improvements in movement accuracy and optimization of instrument trajectories were observed after the Analytic stage. Performance in complex tasks on the APEX simulator improved by 29–33% compared to baseline ($p < 0.01$). In Group III (n = 60), despite initially high performance, additional positive dynamics were observed in coordination, dissection accuracy, and time efficiency after simulation training ($p < 0.05$).

Comparative analysis between groups showed that after completion of the third stage (APEX simulator), the indicators of Groups I and II approached those of Group III, demonstrating the high effectiveness of the training model.

4. Discussion

The obtained results confirm that the step-by-step simulation-based training model is effective in forming laparoscopic skills. Initial skill development using the iModels box trainer creates a solid foundation for subsequent analytic and complex simulation stages. Objective indicators obtained with the LAPARO Analytic trainer play a key role in assessing movement accuracy and time efficiency, enabling a transition from subjective to objective evaluation. Complex scenarios implemented on the LAPARO APEX simulator create an environment close to real clinical practice, simultaneously developing clinical thinking and technical skills.

Compared with the literature, our results are consistent with international studies demonstrating that simulation-based training improves trainee safety and effectiveness prior to clinical practice.

5. Conclusions

1. The step-by-step simulation-based training model was found to be scientifically and practically effective for the systematic formation of practical skills in laparoscopic surgery.

2. The iModels box trainer plays a significant role at the initial stage of laparoscopic education by developing hand-eye coordination, instrument handling, and spatial thinking.
3. The LAPARO Analytic trainer enables objective assessment of movement accuracy, time efficiency, and technical errors, reducing subjectivity in the training process.
4. The LAPARO APEX simulator allows performance of complex laparoscopic tasks in conditions close to real clinical practice, contributing to the development of advanced technical skills and clinical reasoning.
5. Dividing trainees into groups based on preparation level increases training effectiveness, with the highest skill dynamics observed among inexperienced trainees.
6. Statistical analysis confirmed that changes observed at all stages were significant ($p < 0.05$), scientifically validating the effectiveness of the simulation-based training model.
7. The study objectives were fully achieved, and the obtained results enable development of practical recommendations for improving laparoscopic education.
8. The proposed simulation-based training model is recommended for wide implementation in medical universities, simulation centers, and continuing professional development courses.

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