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Design and implementation of modular laparoscopic general surgery models for surgical education

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Appendectomy, cholecystectomy, and inguinal herniorrhaphy are fundamental procedures in general surgery. These surgeries help trainees develop essential surgical skills, including technical proficiency and surgical planning. In this study, we aimed to design and produce modular laparoscopic surgical training models tailored to the needs of surgical education. Modular laparoscopic models for appendectomy, cholecystectomy, and inguinal herniorrhaphy were developed. The cholecystectomy and appendectomy models consisted of two components: a frame and a module, whereas the herniorrhaphy model included a pelvic cavity and peritoneum. A surgical resident with two years of laparoscopic experience at the Department of Surgery at Severance Hospital evaluated the simulators. The modular laparoscopic surgical training models developed in this study are cost-effective, realistic, and capable of precisely simulating surgical environments. These models provide an effective educational tool for enhancing surgical training.

Keywords: Appendectomy, Cholecystectomy, Herniorrhaphy, Minimally invasive surgical procedures, Anatomic models

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INTRODUCTION

Since the late 19th century, when the formal surgical training system in the United States was established, surgical education has undergone significant changes due to advancements in medical knowledge, legal regulations, trainee experience, and technological progress [1]. The introduction of minimally invasive surgery has had a substantial impact on surgical training system.

Laparoscopic surgery, widely adopted in clinical practice, offers advantages in patient recovery compared to open surgery. However, mastering laparoscopic techniques requires overcoming a more complex learning curve than open surgery due to the fulcrum effect [2]. As a result, the development of simulation models to enhance laparoscopic skills has become essential.

Early simulation models focused on teaching the technical principles of the laparoscopy, such as suturing, tying, dissection, clipping, and cutting. However, these models were simplistic and did not account for clinical environments, including anatomical structures [3].

With advancements in engineering technology, training models have evolved significantly. Among these, two major approaches have merged: three-dimensional (3D)-printing bench novels and virtual reality (VR) simulators [4–6]. These models provide a more realistic training environment, offering complex structures and anatomical variations tailored to individual patient characteristics [5].

Cholecystectomy, appendectomy, and inguinal herniorrhaphy are fundamental procedures in the general surgery. Training in these surgeries develop essential surgical skills such as operative design and technique. Consequently, numerous simulation models have been designed to replicate real clinical scenarios [4,5,7].

However, cost remains a crucial factor in developing surgical simulation models, particularly for in educational purposes. Although clinical fidelity is important, educational simulators prioritize generalizability to accommodate students and residents [3,8]. Therefore, this study aimed to design and produce a modular laparoscopic training model that meets the needs of surgical education.

OPERATIVE PROCEDURES

Creation of the simulators

Cholecystectomy

The cholecystectomy model consists of two main components: a frame and a module. The frame includes the liver, common bile duct, and cystic artery, whereas the module consists of the gallbladder, cystic plate, cystic duct, and cystic artery. The hepatic biliary system was cast using silicone rubber, and silicone casting was performed using a colorant. To assemble the frame and module, yellow-colored slime was used to simulate connective tissue dissection. This material was placed in an assembly simulator that connected the cystic duct to the liver, representing the hilar structure around Calot's triangle (Fig. 1A, B; Supplementary Video 1).

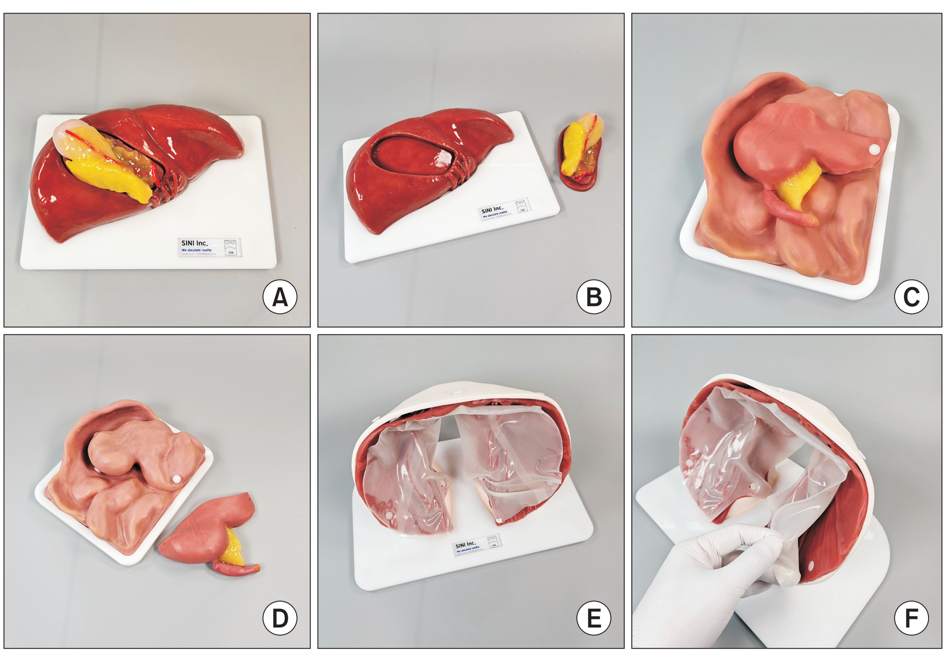

Fig. 1. Modularly designed simulator models. (A, B) Cholecystectomy, (C, D) appendectomy, and (E, F) inguinal herniorrhaphy.

Appendectomy

The appendectomy model consists of a frame and a module. The frame includes the terminal ileum, cecum, and ascending colon, whereas the module replicates the appendix and part of the cecum. The simulator was cast using silicone rubber, with the module positioned over the frame. Slime was placed in the mesoappendix to simulate the appendicular artery, appendix, and cecum, allowing realistic connective tissue division (Fig. 1C, D; Supplementary Video 2).

Herniorrhaphy

The herniorrhaphy model includes a pelvic cavity and peritoneum. The pelvic frame was fabricated using polylactic acid plastic, with iliac, deep epigastric, gonadal vessels, as well as vas deferens, made from silicone rubber and fixed within the pelvic frame. The peritoneum was created using plastic wrap, which was secured to the cavity and fused by striking (Fig. 1E, F; Supplementary Video 3).

Several domain experts who were experienced in their specialties, such as hepato-biliary and pancreatic, colorectal, gastrointestinal, and pediatric surgery for more than 5 years participated in creating the simulators and tried to improve the quality of the models, especially in terms of realism. As a result, several versions of the models have been created, and their quality was enhanced (Supplementary Fig. 1).

Demonstration of the simulators

A surgery resident with 2 years of experience in laparoscopic surgery from the Department of Surgery at Severance Hospital tested the simulators (Supplementary Videos 1–3).

DISCUSSION

An ideal laparoscopic simulator should: (1) help beginners understand the principles of laparoscopic surgery, (2) enhance proficiency in laparoscopic instrumentation, (3) improve safe dissection techniques, and (4) facilitate laparoscopic suturing and tying [1,3,8]. This study aimed to enhance surgical education by developing simulators aligned with these principles. Cholecystectomy, appendectomy, and herniorrhaphy were selected due to their high frequency in general surgery training, allowing trainees to practice using these models.

Recent simulation models fall into two primary categories: VR models and 3D-printed bench models, each with distinct advantages and limitations [4–6]. Bench models are cost-effective and portable but offer low fidelity and a standard type of model. Additionally, some parts require periodic replacement. Conversely, VR models provide diverse anatomical variations and enable surgical performance assessments but are costly and lack tactile realism [2].

Given that these models were designed for surgical education, their primary function was to train basic surgical skills, including dissection, cutting, tying, and suturing, in a realistic clinical setting. Studies indicate that bench models are superior in transferring fundamental skills to beginners [9]. Moreover, cost considerations are essential when developing an educationally viable model [3]. Therefore, our simulation models were based on the bench model, with design modifications to address traditional bench simulator limitations while incorporating the advantages of VR models.

One solution to overcome the limitations of the bench model is modularity. Although cost is an important factor for educational simulators, prioritizing affordability often reduces simulator fidelity [3]. Therefore, the proposed model aimed to balance cost and practicality. The modular design allowed for greater versatility, with module production costs accounting for only 5%–10% of the total simulator cost. This approach enabled high-quality simulation while maintaining affordability. Each module cost was similar to those of previously reported simulation models, with prices of around 30$. Although the previous products were dry lab models, the price was almost the same as our modules [7,10].

Additionally, the modular design allowed for the creation of various anatomical configurations. For example, the appendectomy model could replicate different appendicitis locations such as retrocecal, subcecal, and pre-ileal variants. Similarly, the cholecystectomy model could accommodate different anatomical relationships between the arterial and biliary structures while maintaining affordability [5].

While our models aimed to balance the limitations of bench models through modularity, certain constraints remained. First, although their effectiveness was demonstrated and recorded, further qualitative and quantitative evaluations are necessary. Especially since the model was evaluated by only a single surgical resident with two years of laparoscopic surgery experience, its generalizability is limited. Further studies should assess trainee performance using these models in terms of surgical skills, learning curves, or error rate reduction. Second, our simulators do not support electrocautery. However, this limitation is inherent to bench models, and our design focused on minimally invasive dissection, cutting, tying, and suturing techniques. Nonetheless, these models offer a valuable alternative for trainees beginning minimally invasive surgery.

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In conclusion, our modular laparoscopic surgical models provide a cost-effective, realistic, and adaptable training tool for surgical education. These models enable trainees to develop essential laparoscopic skills in an environment that balances affordability with clinical fidelity.

Notes

Ethics statement

This research did not require an approval from Institutional Review Board because this is not human subjects research.

Authors' contributions

Conceptualization, Methodology, Visualization, Project administration: SHK
Funding acquisition, Supervision: CMK
Resources: SHK, SSC, IGH, HSK
Writing–original draft: SHK
Writing–review & editing: SSC, HSK, CMK
All authors read and approved the final manuscript.

Conflict of interest

Ho Seung Kim, serving as an Editorial Board member of *Journal of Minimally Invasive Surgery*, did not participate in the review process of this article. No other potential conflicts of interest pertinent to this article were reported.

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Data availability

The data presented in this study are available upon reasonable request to the corresponding author.

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Supplementary materials

Supplementary materials can be found via https://doi.org/10.7602/jmis.2025.28.2.103.

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