Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Título Del Artículo (Inglés): 3d Printed Supramesocolic Laparoscopic Simulator for the Choledochoduodeno Anastomosis: Proposal for a Model

Miguel Vassallo Palermo
Universidad central de ve
Aquiles Ramón Molero Chacón
aquilesramonmolero@gmail.com

Universidad central de ve
José Leonardo Morao Pompilli
Universidad central de ve
Alexis Oliveros Grimán
Universidad central de ve

Research Article

Keywords: Supramesocolic, choledochoduodenostomy, simulation, 3D printing, laparoscopic simulator

Posted Date: June 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10033567/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

TÍTULO DEL ARTÍCULO (INGLÉS): 3D PRINTED SUPRAMESOCOLIC LAPAROSCOPIC SIMULATOR FOR THE CHOLEDOCHODUODENO ANASTOMOSIS: PROPOSAL FOR A MODEL

SIMULADOR LAPAROSCÓPICO SUPRAMESOCÓLICO DE COLÉDOCO-DUODENO ANASTOMOSIS LATEROLATERAL EN IMPRESIÓN 3D: PROPUESTA DE MODELO.

Autor: Miguel Vassallo Palermo

ORCID: 0009-0009-2444 1058

Correo: miguelvassallop@gmail.com Telef: 0416-6187768

Dirección: Caracas, Distrito Capital, Venezuela

Hospital Universitario de Caracas. Cátedra de Clínica y Terapéutica Quirúrgica ¨B¨ Especialista en Cirugía General. Jefe de servicio de Cirugía II.

Profesor Titular de la Universidad Central de Venezuela

Autor: Aquiles Ramon Molero Chacón

ORCID: 0009-0009-1147-0319

Correo: aquilesramonmolero@gmail.com Telef: 0414-7282862

Dirección: Caracas, Distrito Capital, Venezuela

Hospital Universitario de Caracas. Cátedra de Clínica y Terapéutica Quirúrgica ¨B¨ Residente de cuarto año de Cirugía General.

Autor: José Leonardo Morao Pompilli

ORCID 0009-0009-2444-1058

Correo: joselmorao@gmail.com Telef: 0414-0516177

Dirección: Caracas, Distrito Capital, Venezuela

Hospital Universitario de Caracas. Cátedra de Clínica y Terapéutica Quirúrgica ¨B¨ Residente de cuarto año del postgrado de Cirugía General.

Autor: Alexis Oliveros Grimán

ORCID 0009-0005-0202-9805

Correo: alexisoliverosucv@gmail.com Telef: 0424-1476585

Dirección: Caracas, Distrito Capital, Venezuela

Hospital Universitario de Caracas. Cátedra de Clínica y Terapéutica Quirúrgica ¨B¨ Especialista en Cirugía General.

Profesor de la Universidad Central de Venezuela

3D PRINTED SUPRAMESOCOLIC LAPAROSCOPIC SIMULATOR FOR THE CHOLEDOCHODUODENO ANASTOMOSIS: PROPOSAL FOR A MODEL

Abstract: Minimally invasive simulation-based training represents a fundamental means for education in the field of surgery, to acquire skills that will be necessary in daily professional practice. **Objective:** To develop a proposal for a 3D-printed supramesocolic laparoscopic simulator model to recreate a side-to-side choledochoduodenostomy (CDA) using the Sasse technique. **Methods:** A prospective and longitudinal cohort study was conducted. The work consisted of 25 practical sessions which were evaluated by applying the GOALS scale and measuring the execution time. **Results:** The 3D simulation model allows for the recreation of the steps to perform the CDA, with a statistically significant improvement found in the scores of the items on the GOALS scale as the practical sessions were carried out. There was a significant inversely proportional correlation between the number of practices and the time taken to develop the skill. **Conclusion:** The proposed model allowed for the recreation of the steps of the CDA, in addition to enabling the development of skills and abilities in advanced laparoscopic surgery. **Keywords:** Supramesocolic, choledochoduodenostomy, simulation, 3D printing, laparoscopic simulator.

SIMULADOR LAPAROSCÓPICO SUPRAMESOCÓLICO DE COLÉDOCO-DUODENO ANASTOMOSIS LATEROLATERAL EN IMPRESIÓN 3D: PROPUESTA DE MODELO.

Resumen: El entrenamiento basado en la simulación mínimamente invasiva representa un medio fundamental para la formación en el campo de la cirugía, para adquirir destrezas que serán necesarias en la práctica diaria profesional. **Objetivo:** Elaborar una propuesta de modelo de simulador laparoscópico supramesocólico en impresión 3D para recrear una colédoco-duodeno anastomosis (CDA) laterolateral mediante la técnica de Sasse. **Métodos:** Se realizo un estudio de corte prospectivo y longitudinal. El trabajo constó de 25 sesiones prácticas las cuales fueron evaluadas aplicando la escala GOALS y medición del tiempo de ejecución. **Resultados:** El modelo de simulación en 3D, permite recrear los pasos para realizar la CDA, encontrándose una mejora estadísticamente significativa en los puntajes de los ítems en la escala de GOALS conforme se realizaron las sesiones prácticas. Hubo correlación significativa inversamente proporcional entre el número de prácticas y el tiempo en desarrollar la habilidad. **Conclusión:** El modelo propuesto permitió la recreación de los pasos de la CDA, además de permitir el desarrollo de habilidades y destrezas en la cirugía laparoscópica avanzada. **Palabras clave:** Supramesocólico, colédoco-duodeno anastomosis, simulación, impresión 3D, simulador laparoscópico.

3D PRINTED SUPRAMESOCOLIC LAPAROSCOPIC SIMULATOR FOR THE CHOLEDOCHODUODENO ANASTOMOSIS: PROPOSAL FOR A MODEL

Introduction

Laparoscopic surgery is a widely accepted and utilized minimally invasive surgical approach that offers multiple benefits, including reduced postoperative pain, shorter hospital stays, and faster patient recovery with a quicker return to daily activities. However, the perceptual shifts relative to open surgery—such as a two-dimensional visual field, altered depth perception, diminished tactile feedback, hand-eye coordination challenges, and a reduced range of motion—pose significant difficulties for professionals lacking adequate training. The dexterity required for laparoscopic surgery is not innate; it must be acquired and perfected through structured training, as its complexity and non-intuitive nature make it difficult to master solely through observation or textual analysis. [1,2]

Following the advent of minimally invasive surgery and the integration of new technologies into the surgical field, the concept of the learning curve has become widely recognized. This curve may be relatively short when mastering the technical skills of a specific intervention; however, it can be protracted and slow for other procedures that are performed less frequently. Simulation serves as a fundamental tool for acquiring basic and advanced neuro-psychomotor skills in minimal access surgery, and mastering these skills is indispensable before embarking on the learning curve of a specific surgical procedure. [3,4]

Given the variable and complex nature of human anatomy, three-dimensional (3D) printing technology emerges as an ideal solution to optimize surgical preparation and planning. 3D printing encompasses a suite of additive manufacturing technologies capable of generating products applicable to various medical fields, highlighting its role in surgical training. [5,6] Within this context, 3D-printed anatomical models offer a superior alternative to traditional cadaveric methods, mitigating significant limitations regarding availability and high costs, while extending their application to specialized fields such as advanced laparoscopic training. [7,8]

Cholelithiasis currently constitutes a global public health problem, affecting approximately 15% of the world's population. Complications derived from this pathology vary, including biliary colic, acute cholecystitis, acute pancreatitis, choledocholithiasis, and even gallstone ileus. Although Endoscopic Retrograde Cholangiopancreatography (ERCP) is the first-line treatment for most cases of choledocholithiasis, complex scenarios demand a definitive surgical solution. In cases of primary and recurrent choledocholithiasis—particularly those involving multiple stones larger than 1 cm in the distal common bile duct and presenting with significant bile duct dilation exceeding 2 cm—choledochoduodenostomy (CDD) is established as the surgical intervention of choice. However, this procedure is not routinely performed by surgeons in training. [9,10]

A prior literature review conducted across the PubMed, Cochrane Library, SciELO, and Google Scholar electronic databases for scientific articles (both original research and reviews) published in English and Spanish yielded no results for a side-to-side choledochoduodenostomy training model that utilizes 3D printing technology to recreate the necessary steps of this procedure for subsequent implementation in daily surgical practice

General Objective

- To develop a 3D-printed supramesocolic laparoscopic simulator model proposal for side-to-side choledochoduodenostomy.

Specific Objetives

- To design and manufacture the inorganic, 3D-printed supramesocolic model to anatomically replicate the conditions required for a side-to-side choledochoduodenostomy.
- To replicate the surgical steps of the Sasse technique for side-to-side choledochoduodenostomy using the developed 3D-printed simulation model.
- To assess laparoscopic surgical skills and dexterity acquired during each practical session using the Global Operative Assessment of Laparoscopic Skills (GOALS) scale.
- To measure the operative execution time of each practical simulation session of the choledochoduodenostomy technique on the 3D-printed model.
- To determine participant performance throughout the training sessions by correlating GOALS scale scores with their respective operative execution times.
- To evaluate participant satisfaction regarding the training sessions using a structured Likert scale.

Procedures

For the execution of this project, a laparoscopic training simulator was utilized, consisting of three primary components: a 3D-printed hybrid supramesocolic model, a laparoscopic box trainer, and a low-cost, custom-made choledochoscope.

1. 3D-Printed Hybrid Supramesocolic Model

This organ-specific simulator is designed to be adapted into the laparoscopic box trainer. Its structural configuration allows for the replication and execution of multiple surgical procedures within the supramesocolic area, specifically side-to-side choledochoduodenostomy.

Internal Structure and Dimensions

- Composition: The simulator comprises a total of 27 modular pieces, featuring a planimetric base layout generated from detailed engineering blueprints. This manufacturing process ensures both dimensional fidelity (length: 20 cm, width: 20 cm, height: 3 cm) and a highly reproducible modular structure (The design blueprints are displayed in Figure 1).

- Base: It features a semi-U-shaped base equipped with fixation holes to secure the anatomical structures. Its dimensions allow it to be adapted to various commercial or custom laparoscopic box trainer models.

- Manufacturing: The model is manufactured using 3D printing technology, utilizing Polylactic Acid (PLA) and Thermoplastic Polyurethane (TPU) filaments.

Anatomical Structures

The key anatomical structures of the supramesocolic region are arranged chronologically upon the base:

- Primary Organs: Stomach and duodenum.

- Biliary Tract: Includes the accessory biliary tract (gallbladder and cystic duct), the right

and left hepatic ducts, and the common bile duct.

- Vascular System: The portal venous system is fully simulated.

Hybrid Components (Rubber Tubing): To faithfully replicate the tactile feedback and realism of the biliary tract, duodenum, and portal system, hybrid elastomeric components are integrated into the model:

- Common Bile Duct and Duodenum Support: A 9-cm-long support channel is engineered to accommodate a 10-mm diameter rubber tube.
- Portal System Support: Similarly, a specific support channel is designated for the portal venous system, which also accommodates a 10-mm diameter rubber tube.
- Fixation: The structural stability of these hybrid components is secured by mechanical pins located at each end of the support channels.

2. **Laparoscopic Box Trainer** The surgical training was conducted within a standard laparoscopic box trainer:

- **Dimensions:** The trainer features a base measuring 40 cm in length by 34 cm in width.
- **Structure:** It consists of a base floor, two side walls, and a top ceiling panel.
- **Instrument Access:** The top panel features access ports arranged in a triangular configuration for the placement of three 5-mm trocars. Additionally, the side walls include a dedicated port for the surgical assistant.
- **Instrumentation:** Standard laparoscopic instruments required to replicate the procedure are introduced through these ports, including an atraumatic grasper, a Maryland dissecting forceps, a needle holder, and laparoscopic scissors. One of the designated ports is assigned specifically for assistant intervention.

3. **Custom-Made Choledochoscope** The custom-made choledochoscope is composed of a 3-cm tubular optical element featuring a 1080p High-Definition (HD) resolution capability. It is equipped with adjustable-brightness LED lights surrounding the camera lens and provides a 0° angle of view. The proximal end of the instrument features a USB port, ensuring compatibility with laptop computers. The device has a total flexible probe length of 200 cm and an outer diameter of 3 mm (See Figure 2).

Surgical Training Protocol and Technical Steps A total of 25 training sessions were conducted in the laparoscopic box trainer. The side-to-side choledochoduodenostomy using the Sasse technique was replicated on the described model through the following sequential steps:

1. **Laparoscopic Visualization:** Initial laparoscopic visualization of the 3D-printed supramesocolic model within the box trainer (Figure 3).
2. **Kocher Maneuver Replication:** The Kocher maneuver was replicated to mobilize the simulated duodenal conduit using a Maryland dissecting forceps and laparoscopic scissors. An incision was performed on the membrane simulating the peritoneum (for which Elastoplast® was utilized) along the right lateral border of the second portion of the duodenum. Utilizing a combination of blunt dissection (grasper and Maryland forceps), the duodenum was separated from the peritoneum (Figures 3-A, 3-B).
3. **Choledochotomy:** Utilizing laparoscopic scissors and an atraumatic grasper, a 1.5-cm longitudinal incision was made along the main axis of the conduit simulating the supraduodenal common bile duct

(Figures 4).

4. **Choledochoscopy:** Direct visualization of the gallstone inside the simulated common bile duct conduit was achieved using the custom-made choledochoscope connected to a secondary monitor (Figures 5-A, 5-B).
5. **Stone Extraction:** The simulated gallstone was extracted externally by applying ascending pressure on the common bile duct conduit using a Maryland forceps at both the proximal and distal levels (Figure 5-C).
6. **Permeability Verification:** Clear patency of the common bile duct conduit was verified following stone extraction by performing a secondary inspection with the custom-made choledochoscope (Figures 5-D, 5-E).
7. **Duodenotomy:** A 1.5-cm longitudinal incision was performed on the simulated duodenal conduit using an atraumatic grasper and laparoscopic scissors, ensuring that both incisions (choledochotomy and duodenotomy) were closely approximated (Figure 6-A).
8. **Primary Anastomotic Stitch:** Utilizing a 4-0 polypropylene suture, a primary stitch was placed at the inferior angle of the choledochotomy and through the midpoint of the medial border of the duodenal incision, securing it with three intraluminal intracorporeal knots (Figures 6-B, 6-C, 6-D, 6-E).
9. **Anchoring Stitches and Traction:** Utilizing two new 4-0 polypropylene sutures, two extraluminal stay (anchoring) stitches were placed without immediate intracorporeal knotting. The first stitch was placed at the midpoint of the inferior border of the common bile duct incision (outside-in) and through the inferior angle of the duodenal incision (inside-out). The second stitch was placed at the medial border of the superior angle of the common bile duct (outside-in) and through the superior angle of the duodenal incision (inside-out). These two tracking sutures were left unknotted to be used by the assistant to apply traction, thereby exposing the posterior wall of the anastomosis in a classic "diamond" or "rhomboid" configuration (Figure 7).
10. **Posterior Wall Anastomosis:** Utilizing a new suture, two interrupted stitches were placed on the posterior wall of the choledochoduodenostomy (inside-out through the posterior wall of the duodenum and outside-in through the posterior wall of the common bile duct). The first stitch was located between the superior and middle points of the duodenal posterior wall, while the second was positioned between the inferior and middle points of the duodenal posterior wall. Each stitch was secured with three intraluminal intracorporeal knots (Figures 8-A, 8-B, 8-C, 8-D, 8-E, 8-F, 8-G).
11. **Posterior Wall Closure Completion:** The two anchoring stay stitches previously placed in Step 9 (lateral aspects of the common bile duct and duodenum) were then knotted to complete the closure of the posterior anastomotic wall, applying three extraluminal knots to each stitch (Figures 8-H, 8-I).
12. **Anterior Wall Closure:** Utilizing a final 4-0 polypropylene suture, three interrupted stitches were placed on the anterior wall of the anastomosis (outside-in through the duodenum and inside-out through the common bile duct) and secured with three extraluminal knots, thereby completing the procedure (Figure 9).

Anastomotic Integrity and Assessment Following the completion of the choledochoduodenostomy, suture integrity and patency were verified using two primary methods. First, an intraluminal inspection of the anastomosis was performed using the custom-made choledochoscope introduced through one of the ends of the simulated biliary tract. Subsequently, for a comprehensive and educational evaluation of the technique, a longitudinal incision was performed on the posterior aspect of the conduit representing the duodenal knee (*genu*). This incision allowed for direct exposure and visualization of the alignment, tension, and pattern of each of the suture lines described in the previous steps, ensuring the correct execution of the anastomosis (Figures 10-A, 10-B, 10-C).

Supervision and Performance Metrics The duration of each training session, as well as operative performance, was supervised by three expert surgeons specializing in advanced laparoscopy. They recorded the execution time for each practical session and evaluated the procedural quality using the Global Operative Assessment of Laparoscopic Skills (GOALS) scale. Additionally, upon completion of the entire training program, a Likert scale was administered to measure the participant's subjective satisfaction regarding the training curriculum (Table 1).

Statistical Analysis

Once the data were collected, a database was compiled using a Microsoft® Excel spreadsheet, into which the scores and completion times recorded during each practical session by the three evaluators were inputted. A quantitative analysis of the scores obtained from the GOALS scale and the execution times across the training sessions was performed; these data were expressed as mean ± standard deviation (SD), median, minimum and maximum values, and coefficient of variation. Absolute and relative frequencies were calculated for qualitative and quantitative variables as deemed appropriate. Additionally, linear trend plots were constructed to evaluate the direction of the ordinal variables to be correlated. All statistical analyses were performed using SPSS version 26 software (IBM Corp., Armonk, NY, USA). Kendall's tau-b non-parametric statistical test was applied, with statistical significance established at $p < 0.05 and high significance at $p < 0.01.

Results

In the proposed 3D-printed supramesocolic laparoscopic simulator model, it was possible to successfully replicate all the sequential steps of the surgical technique as a single, integrated block. The lowest Global Operative Assessment of Laparoscopic Skills (GOALS) score was 9 points recorded during the first session, which progressively increased to a maximum of 25 points by the 25th practice session. A directly proportional and statistically significant positive correlation was observed between the overall score and the chronological number of practice sessions (See Figure 1-A).

Regarding the duration (in minutes) of the simulated surgical procedure, a clear reduction in execution time was demonstrated as the practice sessions progressed. In the initial session, the choledochoduodenostomy (CDD) required a total execution time of 120 minutes, which decreased progressively until the final session, where the CDD was completed in 54 minutes (See Figure 1-B). Consequently, a statistically significant inverse correlation was demonstrated between the session number and technical execution time ($p < 0.001$). When comparing surgical execution time against the GOALS scale scores, the scale metrics exhibited a steady upward trend as training advanced, while operative times consistently decreased. The convergence of these two variables (session duration and GOALS scale score) occurred at practice session 14, establishing the asymptotic crossover point of the learning curve (See Figure 1-C). The correlations between CDD session duration and the acquired GOALS scores were highly significant according to both Kendall's tau-b ($p = 0.000$) and Spearman's rho ($p = 0.000$) coefficients; furthermore, a strong negative relationship was confirmed between session duration and GOALS performance metrics (tau_b = -0.912; rho = -0.975).

Upon completion of the final practical session, the participant's satisfaction level was evaluated using a structured Likert scale. Every single evaluated item achieved a maximum score of 5/5 points, reflecting a response of "highly satisfied" regarding the training received within the established timeframe, the advisory support provided by the instructor in clarifying doubts, and the evaluation methods implemented. Additionally, high satisfaction was reported concerning the technical skills refined through the simulator and the competencies acquired during the procedures, yielding a maximum cumulative score of 30 points. This represents an outstanding level of overall satisfaction with the surgical technique practiced on the proposed model.

Discussion

The integration of simulation is undoubtedly an invaluable tool in the field of surgical education due to its capacity to replicate clinical scenarios in a controlled and safe environment without jeopardizing patient safety. This methodology promotes an accelerated learning curve while fostering the development and refinement of both technical and non-technical skills, such as decision-making, teamwork, effective communication, and leadership. Three-dimensional (3D) printing provides an ideal medium to create procedure-specific simulations, as demonstrated by Burdal and Schwab in 2016. In their respective works, they utilized this technology to recreate the common bile duct for exploration. Aligned with their findings, the present study successfully replicated the sequential steps of a side-to-side choledochoduodenostomy (CDD) using a 3D-printed hybrid model, further underscoring the critical importance of these models in surgical education. Similarly, in

accordance with the study by Allan et al., who successfully replicated a dilated bile duct resulting from a congenital choledochal cyst, our approach focused on developing a 3D model to simulate a CDD. This highlights the potential of additive manufacturing technology to provide a tangible, three-dimensional visualization of the complex supramesocolic anatomy, coupled with the opportunity to practice the core technical steps of the CDD, thereby offering significant advantages for technical skill acquisition among surgeons-in-training [11,12,13,14].

In 2021, Rubín and Vassallo demonstrated the feasibility of replicating a laparoscopic gastrostomy technique using a 3D-printed model. Consistent with our results, their findings revealed that as the number of practice sessions increases, there is a subsequent reduction in execution time and a concurrent increase in the Global Operative Assessment of Laparoscopic Skills (GOALS) scores. Our work proposes an extension of this utility by designing models that not only represent the supramesocolic anatomy to recreate the steps of a CDD but also enable the optimization of operative times and the objective assessment of technical skills via the validated GOALS scale [15,16,17].

Furthermore, the study conducted by Xia et al. (2023) highlights the crucial role of assessment scales within the scope of 3D-printed surgical simulation. Their research focused not only on the development and validation of a 3D-printed model for laparoscopic choledochojejunostomy but also integrated an objective evaluation of surgical performance using a Likert-type questionnaire and operative time measurements. In contrast to the study by Xia et al., which focused on a different anastomotic model (choledochojejunostomy) and primarily relied on operative time as a proxy for improvement, our study implemented the GOALS scale within a supramesocolic model specifically designed to replicate the technical steps of a side-to-side choledochoduodenostomy, allowing for a more granular evaluation of the technical skills directly relevant to this specific procedure. This multifaceted approach demonstrates how structured assessment scales provide a rigorous framework to establish simulator validity and, more importantly, to quantify the learning curve and technical skill acquisition of residents, ensuring they achieve a demonstrable level of proficiency before performing these complex procedures in a real-world clinical setting [18].

Conclusions

The learning curve for less frequent surgical procedures, such as laparoscopic choledochoduodenostomy (CDD), is inherently protracted. The 3D-printed supramesocolic laparoscopic simulation model for side-to-side CDD successfully enables the precise replication of the sequential steps of this complex surgical technique while establishing a quantifiable framework to assess its effectiveness as an advanced training tool.

The primary contribution of this resource lies in providing a procedure-specific, highly reproducible simulation model that outperforms traditional cadaveric methods—which are hindered by high costs and restricted availability—as well as basic box trainers that lack the necessary anatomical specificity. The hybrid design of the model, which integrates rigid 3D-printed structures with elastomeric rubber tubing to simulate the biliary tract and duodenum, endows the simulator with realistic tactile feedback. This allows surgeons-in-training to practice dissection, duodenal mobilization, and, crucially, intracorporeal suturing and knot-tying within a confined supramesocolic field. Furthermore, by incorporating a low-cost, custom-made choledochoscope, the simulator enables the rehearsal of a complete operative sequence. This includes intraoperative choledochoscopy for gallstone extraction and post-anastomotic patency verification, which are essential steps for the comprehensive management of complex choledocholithiasis.

The results demonstrate a highly significant correlation between the number of practice sessions and overall surgical performance, as evidenced by a progressive increase in GOALS scale scores (from 9 to 25 points) and a concurrent reduction in execution time (from 120 to 54 minutes). The asymptotic crossover point observed at practice session 14 strongly suggests a critical inflection point in the learning curve, marking where the participant achieves a substantial enhancement in technical efficiency and procedural quality. The implementation of the validated GOALS scale alongside precise time tracking provides an objective, standardized evaluation of neuro-psychomotor skills, allowing instructors to monitor trainee progress in a quantifiable manner before transferring these clinical skills to the real operating room environment.

Finally, the maximum score achieved on the Likert scale underscores the participant's highly positive perception regarding the utility and relevance of this training curriculum, which is paramount for sustaining motivation and engagement during the acquisition of complex technical skills. This 3D simulator is not merely an academic prototype; it is a high-value educational tool that, due to its anatomical specificity and capacity to recreate advanced surgical scenarios, should be considered an indispensable resource in advanced laparoscopic training programs. Ultimately, this model enables residents to shorten their learning curves and enhance patient safety during the execution of a choledochoduodenostomy, driving innovation in surgical education through the use of 3D printing as an advanced, target-oriented pedagogical resource.

Recommendations

It is suggested to implement the proposed model as a structured learning instrument for surgeons-in-training, with the primary goal of developing advanced skills and dexterity in minimally invasive surgery. This will enable the rehearsal of complex procedures that are infrequently performed during standard residency training, within a safe, anxiety-free environment. Furthermore, it is necessary to continue developing simulation prototypes utilizing 3D printing technology that incorporate current technological advancements, thereby sustaining a continuous line of research.

Ethical Approval The present research study was conducted in strict accordance with the four principles of bioethics established by Beauchamp and Childress.

Conflict of Interest The authors declare no conflicts of interest.

References

1) Sosa E, Hasan Z, Jiménez X, Villegas M. Papel de la simulación en la educación quirúrgica de mínimo acceso. Rev Hosp Jua Mex. 2014;81(4):245-249.

2) Aponte M, Cárdenas R, Salvador N. Simulador laparoscópico como herramienta de aprendizaje. Rev Fac Med (Caracas). 2009;32(2):150-157.

3) Ferrufino L, Cohen V, Buckel E, Crovari E, Pimentel M, et al. Simulación en cirugía laparoscópica. Cir Esp. 2015;93(1):4-11. doi:10.1016/j.ciresp.2014.02.012

4) Cantele H, Sánchez A. Cirugía laparoscópica básica y avanzada. Caracas, Venezuela: Editorial Livrosca; 2010.

5) Estepa J, Bueno M, León A, González J. Construcción de un simulador artesanal para la adquisición de habilidades en cirugía laparoscópica. Medisur. 2020;18(1):63-71.

6) Perdomo G, Penagos A. Application of regenerative medicine and 3D bioprinting in urology. Actas Urol Esp (Engl Ed). 2022;46(6):323-328. doi:10.1016/j.acuroe.2022.03.006

7) Galbiati A. Impresión 3D, tecnología y polímeros. AADECA Revista. 2019;(12):18-24.

8) Ventola CL. Medical applications for 3D printing: Current and projected uses. P T. 2014;39(10):704-711.

9) Angelis B, Núñez B, Rodríguez E. Colecistectomía Laparoscópica difícil: tratamiento quirúrgico. Rev Postgrado. 2023;12(1):e354. doi:10.37910/RDP.2023.12.1.e354

10) Ferraina P, Merello J. Anastomosis bilio-digestivas. Sociedad Argentina de Cirugía Digestiva. 2009;IV(461):1-14.

11) Burdall OC, Makin E, Davenport M, Ade-Ajayi N. 3D printing to simulate laparoscopic choledochal surgery. J Pediatr Surg. 2016;51(5):828-831. doi:10.1016/j.jpedsurg.2016.02.093

12) Schwab B, Rooney D, Hungness E, Barsness K. Preliminary evaluation of a 3D-printed laparoscopic common bile duct injury model for pediatric surgery education. J Laparoendosc Adv Surg Tech A. 2016;26(10):832-835. doi:10.1089/lap.2016.0121

13) Allan A, Keally C, Squelch A, Wong YH, Yeong CH, Sun Z. Patient-specific 3D printed model of biliary ducts with congenital cyst. Quant Imaging Med Surg. 2019;9(1):86-93. doi:10.21037/qims.2018.12.04

14) Vassallo M, Morao J, Linares S. Habilidades no técnicas en cirugía: Una revisión de la literatura. Rev Colomb Cir. 2023;38(4):682-695. doi:10.30944/20117582.2603

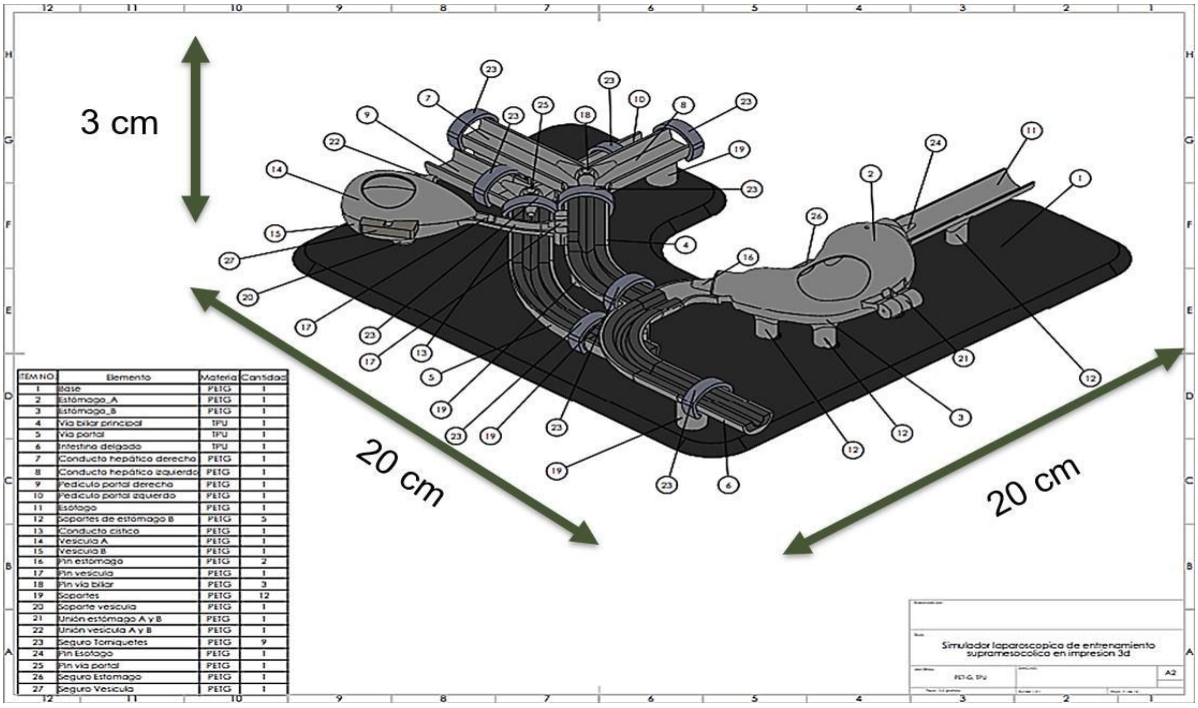
15) Rubín A, Vassallo M. Modelo inorgánico de simulación de gastrostomía laparoscópica con impresión 3D, para adquirir habilidades en sutura intracorpórea. Estudio cuasi-experimental. Rev Venez Cir. 2021;74(2):45-51.

16) Casas C, Zúñiga A, López R, Sánchez A, Gogeascoechea A, et al. 3D printed anatomical models of the cystic duct and its variants, a low-cost solution for an in-house built simulator for laparoscopic surgery training. Surg Radiol Anat. 2021;43(4):537-544. doi:10.1007/s00276-020-02631-3

17) Aguirre I, Cuendis A, Ernesto C, Torres M, Edgardo M, Cárdenas L. Colédoco-duodeno-anastomosis laparoscópica como opción terapéutica en coledocolitiasis compleja. Cir Cir. 2013;81(2):118-124.

18) Xia J, Mao J, Chen H, Xu X, Zhang J, et al. Development and evaluation of a portable and soft 3D-printed cast for laparoscopic choledochojejunostomy model in surgical training. BMC Med Educ. 2023;23(1):77. doi:10.1186/s12909-023-04055-0

Appendices



ITEM NO.	Elemento	Material	Cantidad
1	Base	PETG	1
2	Estómago_A	PETG	1
3	Estómago_B	PETG	1
4	Vía biliar principal	TPU	1
5	Vía portal	TPU	1
6	Intestino delgado	TPU	1
7	Conducto hepático derecho	PETG	1
8	Conducto hepático izquierdo	PETG	1
9	Pedículo portal derecho	PETG	1
10	Pedículo portal izquierdo	PETG	1
11	Esófago	PETG	1
12	Soportes de estómago B	PETG	5
13	Conducto cístico	PETG	1
14	Vesícula A	PETG	1
15	Vesícula B	PETG	1
16	Pin estómago	PETG	2
17	Pin vesícula	PETG	1
18	Pin vía biliar	PETG	3
19	Soportes	PETG	12
20	Soporte vesícula	PETG	1
21	Unión estómago A y B	PETG	1
22	Unión vesícula A y B	PETG	1
23	Seguro Torniquetes	PETG	9
24	Pin Esofago	PETG	1
25	Pin vía portal	PETG	1
26	Seguro Estomago	PETG	1
27	Seguro Vesicula	PETG	1

Figure 1. Planimetric layout of the supramesocolic model, including dimensions and total number of modular pieces. *Source: Authors.*

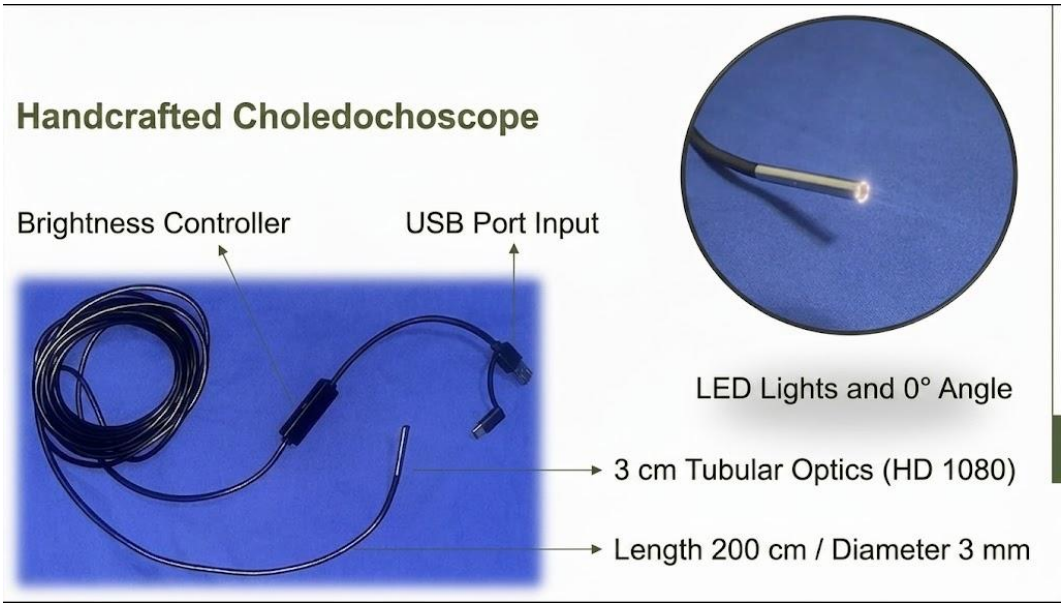


Figure 2. Components and technical specifications of the custom-made choledochoscope, featuring a 3-cm tubular optical element (1080p HD resolution), adjustable LED illumination, and a 200-cm flexible probe. *Source: Authors.*



Figure 3. Visualization of the model within the laparoscopic box trainer. **A:** Incision performed on the membrane simulating the peritoneum along the right lateral border of the second portion of the duodenum. **B:** Blunt dissection utilizing a laparoscopic grasper and Maryland forceps to separate the duodenum from the peritoneum. *Source: Authors.*

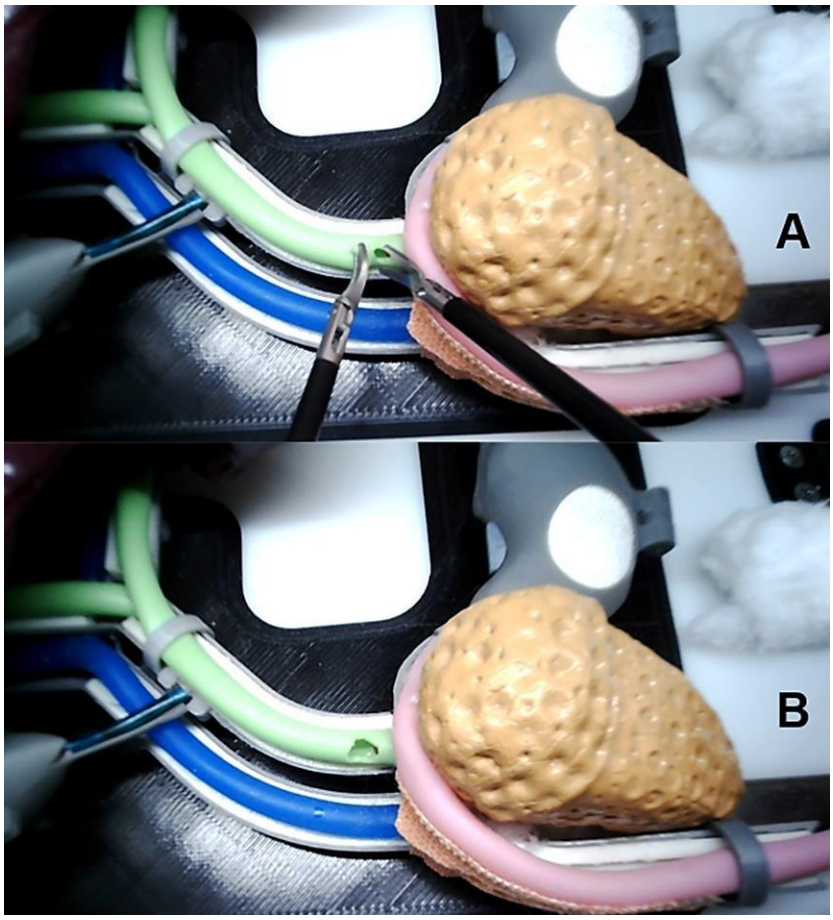


Figure 4. A: A 1.5-cm longitudinal incision along the main axis of the conduit simulating the supraduodenal common bile duct. **B:** Completed choledochotomy. *Source: Authors.*

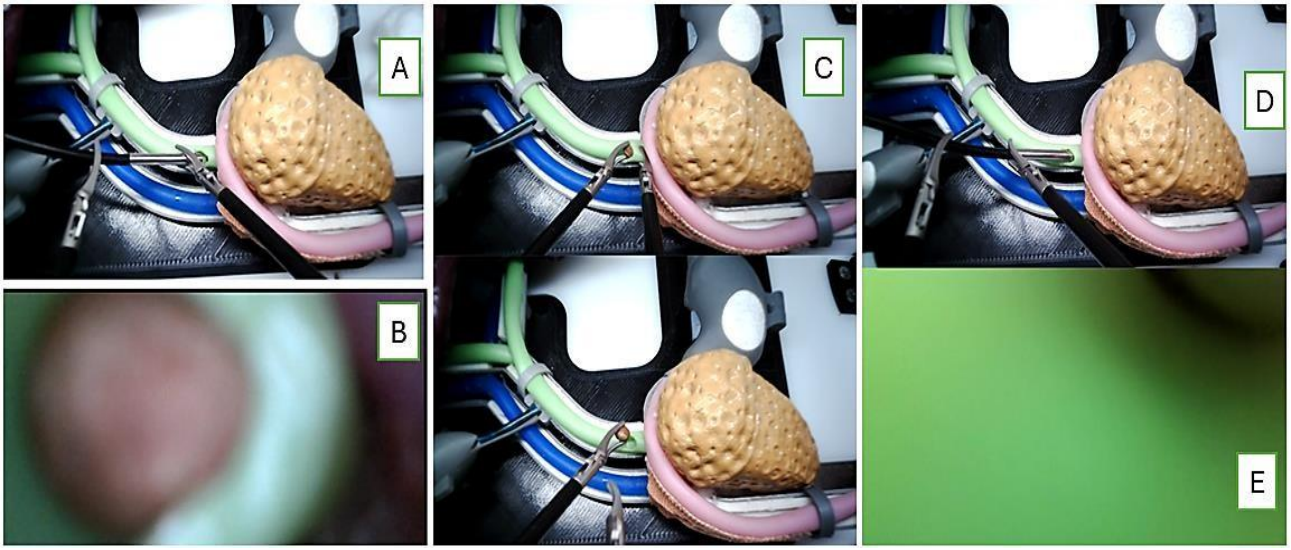


Figure 5. A: Custom-made choledochoscope: laparoscopic view. **B:** Custom-made choledochoscope: endoscopic view. **C:** External extraction of the gallstone from the common bile duct conduit. **D:** Custom-made choledochoscope: secondary laparoscopic verification view. **E:** Custom-made choledochoscope: secondary endoscopic verification view. *Source: Authors.*

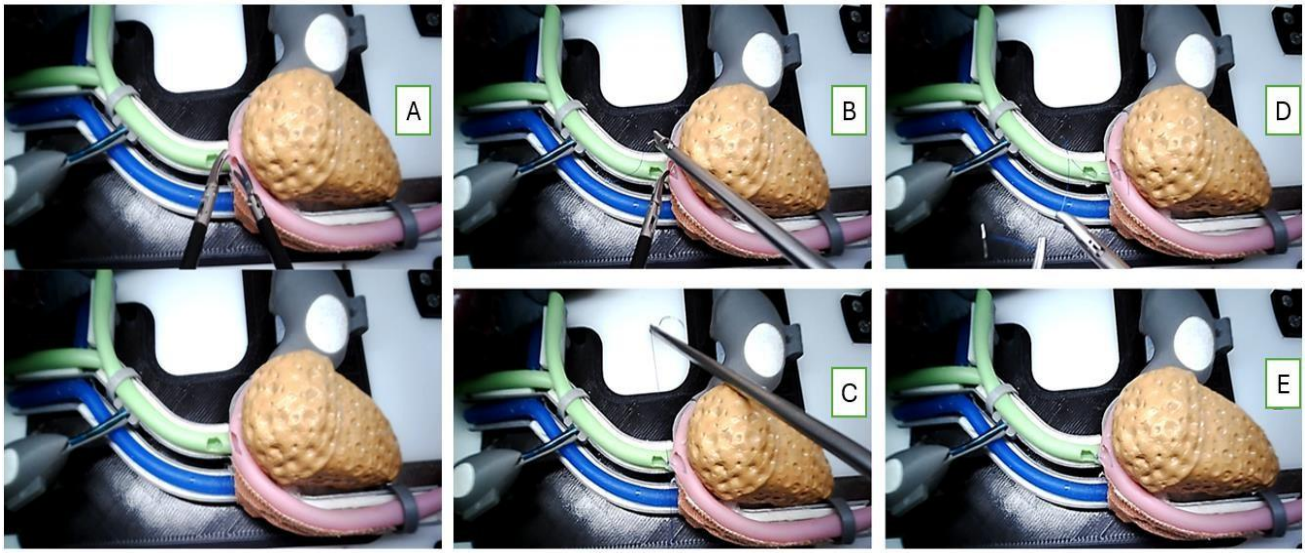


Figure 6. A: A 1.5-cm longitudinal incision performed on the simulated duodenal conduit utilizing an atraumatic grasper and laparoscopic scissors. **B, C, D, E:** Sequential views of the primary stitch placed at the inferior angle of the choledochotomy and through the midpoint of the medial border of the duodenal incision, secured with three intraluminal intracorporeal knots. *Source: Authors.}*

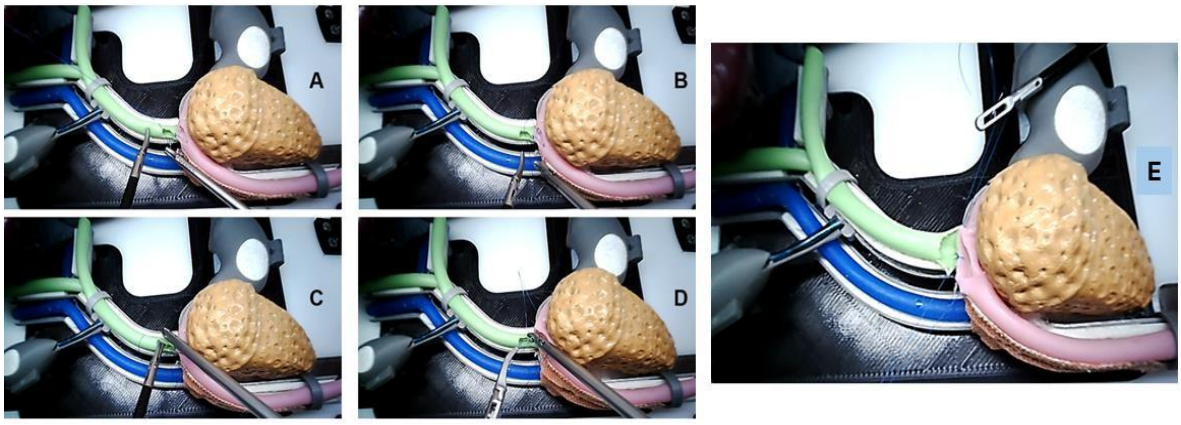


Figure 7. Lateral anchoring stay sutures. A: *First stitch placed through the inferior border of the common bile duct (outside-in).* ***B:*** *First stitch placed through the inferior angle of the duodenum (inside-out).* ***C:*** *Second stitch placed through the superior border of the common bile duct (outside-in).* ***D:*** *Second stitch placed through the superior angle of the duodenum (inside-out).* ***E:*** *Upward traction of the lateral stay sutures applied by the assistant, exposing the anastomosis in a classic rhomboid configuration and facilitating the visualization of the posterior wall. Source: Authors.*

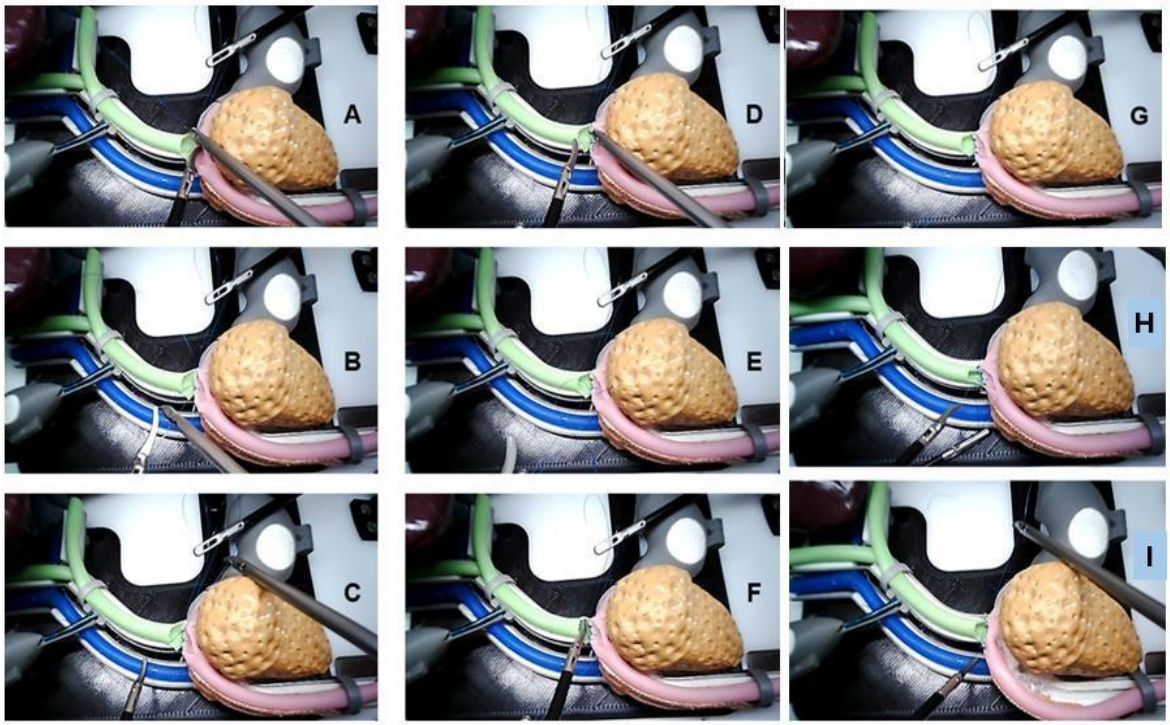


Figure 8. *Sequential steps for the placement of the intraluminal interrupted sutures on the posterior wall of the choledochoduodenostomy.* ***A, B, C:*** *Execution of the first suture placed between the superior and middle points of the posterior duodenal wall.* ***D, E, F:*** *Execution of the second suture placed between the inferior and middle points of the posterior duodenal wall.* ***G:*** *Completed posterior wall of the choledochoduodenostomy.* ***H:*** *Extracorporeal knotting of the superior lateral anchoring stay suture.* ***I:*** *Extracorporeal knotting of the inferior lateral anchoring stay suture to complete the posterior closure. Source: Authors.*

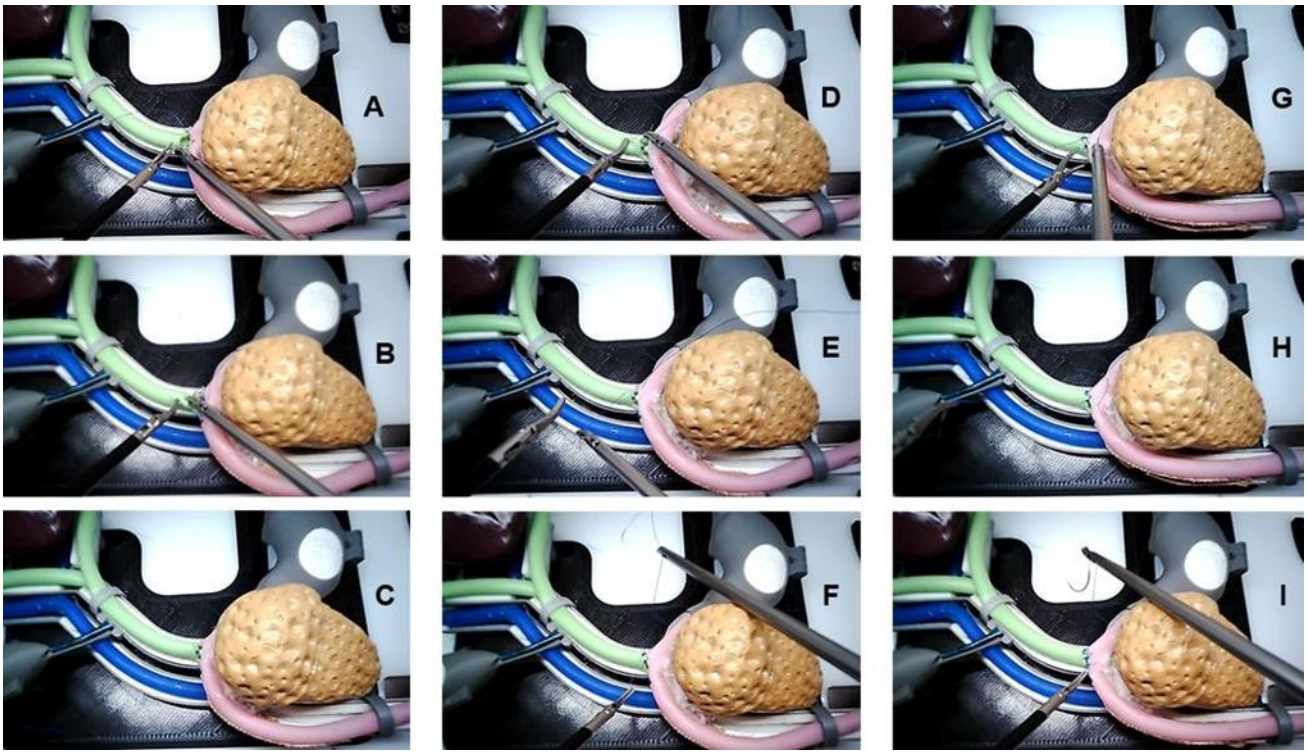


Figure 9. Closure of the anterior wall of the choledochoduodenostomy utilizing three extraluminal interrupted sutures. **A, B, C:** Sequential views of the medial suture placement. **D, E, F:** Sequential views of the superior suture placement. **G, H, I:** Sequential views of the inferior suture placement. *Source: Authors.*



Figure 10. A: Completed choledochoduodenostomy. B: Endoscopic view through the custom-made choledochoscope verifying patency. C: Intraluminal visualization of the anastomosis through a longitudinal incision performed on the posterior wall of the duodenal conduit. Source: Authors.

GOALS Scale

Depth Perception

1	2	3	4	5
Constantly overshoot target, wide movements, correct slowly		Some target misses, but correct quickly		Direction and plane correct, instruments are directed towards the target

Bimanual Dexterity

1	2	3	4	5
Uses only one hand, ignores non-dominant hand, poor coordination between both		Uses both hands, but interaction between both is not optimal		Uses both hands in a complementary manner for optimal exposure

Efficiency

1	2	3	4	5
Many tentative movements, frequent changes in the steps to follow, no progress		Slow but organized and reasonable movements		Confident, efficient, stays focused on target

Tissue Handling

1	2	3	4	5
Abrupt movements, tears tissue, damage to structures, poor control		Reasonable tissue handling, minor damage occurs		Adequate tissue handling, appropriate traction on same

Autonomy

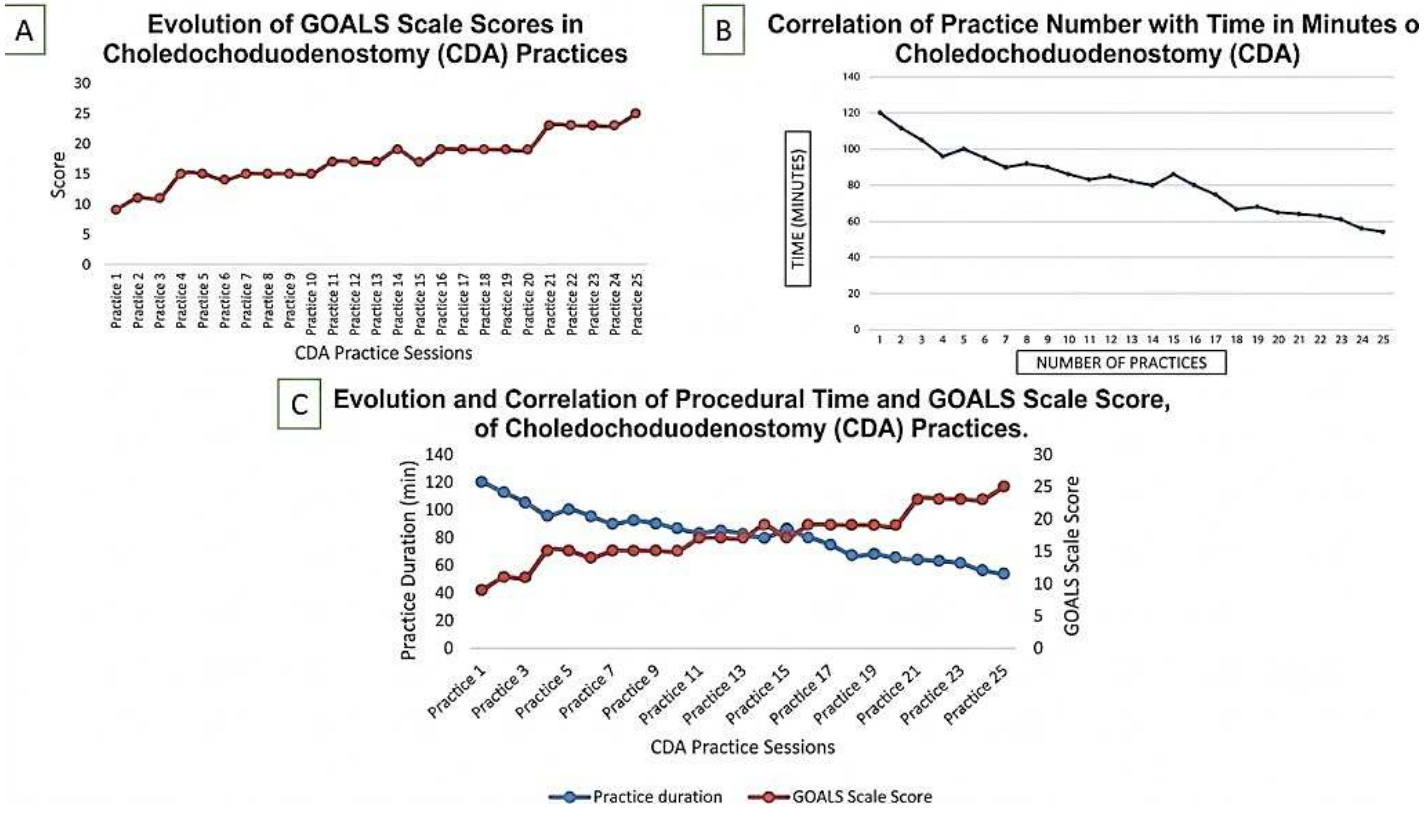
1	2	3	4	5
Incapable of finishing procedure		Capable of finishing task in a safe manner, with some guidance by proctor		Capable of completing task alone, without guidance

Likert Scale

Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
5	4	3	2	1

After the development of the laparoscopic simulation training program, you:	5	4	3	2	1
1. Received sufficient training in the established time	5	4	3	2	1
2. Perceived constant support from proctor/educator during training	5	4	3	2	1
3. Received timely answers to all questions that might arise during training process	5	4	3	2	1
4. Evaluations were developed clearly and precisely	5	4	3	2	1
5. The program deepened previous skills regarding use of laparoscopic simulator	5	4	3	2	1
6. The laparoscopic simulation program strengthens competence for complex procedures	5	4	3	2	1

Table 1. Global Operative Assessment of Laparoscopic Skills (GOALS) Scale and Participant Satisfaction Likert Scale. *Source: Authors.*



Graph 1. A: Evolution of GOALS Scale scores across choledochoduodenostomy (CDA) practice sessions. **B:** Correlation between the number of practice sessions and operative time (in minutes) for choledochoduodenostomy (CDA). **C:** Evolution and dual-axis correlation of procedural time and GOALS Scale scores during choledochoduodenostomy (CDA) practice sessions. *Source: Authors.*