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Research Article

3D-Printed Supramesocolic Laparoscopic Simulator for Roux-en-Y Bihepatic-Jejunostomy: Proposal for a Model

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Abstract

Objective: To develop a laparoscopic supramesocolic simulator of Roux-en-Y bihepato-jejuno anastomosis in 3D printing at the Chair of Clinical and Surgical Therapeutics "B" of the Surgery II Service of the University Hospital of Caracas in the period 2024-2025..

Methods: Prospective and longitudinal study, which consisted of 20 practical sessions with the 3D model evaluated by expert surgeons.

Results: 20 practical sessions were carried out in a laparoscopic black box with the Roux-en-Y bihepato-jejuno anastomosis model. An asymptotic curve was observed between the duration of the bihepatojejunostomy and entero-entero anastomosis and the score obtained using the GOALS scale (tau-B = -0.790). The 3D-printed supramesocolic model is a low cost, highly reproducible tool that provides ideal conditions for the acquisition of surgical skills to recreate a Roux-en-Y bihepato-jejuno anastomosis.

Conclusion: The use of the model allowed the analysis of surgical skills and abilities by applying the GOALS scale as the practices progressed, which in turn translated into the acquisition of surgical skills and abilities necessary for performing this laparoscopic procedure.

Keywords: Simulation, biliary, 3D printing, anastomosis

Introduction

General surgery encompasses a broad spectrum of surgical procedures, including those performed on the digestive system, among which bilioenteric reconstructions stand out. These are highly complex interventions used to restore biliary flow in cases of biliary tree obstruction or injury. This type of intervention requires extreme precision and an extensive knowledge of anatomy by the surgeon. The learning curve to master this type of surgery involves acquiring advanced technical skills and the ability to manage every detail as surgeons gain experience. The success rate of surgical procedures improves with experience, highlighting the importance of continuous training and practice in developing surgical competence [1].

Learning models are fundamental for training competent and safe surgeons. These models range from traditional education based on mentorship and direct observation in the operating room to modern methods incorporating simulators and advanced technology. Traditional surgical learning, known as the Halsted model, allows residents in training to acquire skills under the supervision of experienced surgeons. However, with technological advancements, virtual reality simulators and 3D-printed anatomical models have emerged as valuable tools that allow for repetitive and safe practice of complex procedures without risk to patients. These innovative methods not only accelerate the learning curve but also enhance the precision and confidence of the training surgeon. The combination of traditional and modern techniques creates a comprehensive approach that optimizes teaching and surgical competence [2]. To this end, hundreds of simulators have been created throughout history. One of the most widely used techniques today is the creation of three-dimensional printed models. This technology has not only played a major role in simulation but has also been applied across various branches of medicine, with greater relevance in the surgical field due to its high utility and low cost [3, 4].

Hand in hand with this technology, bilioenteric reconstructions such as laparoscopic Roux-en-Y bihepatic-jejunostomy allow overcoming the procedural difficulties as well as the technical challenges inherent to laparoscopic surgery, such as two-dimensional vision, haptics, the fulcrum effect, and decreased tactile sensation, which can be overcome by 3D models that allow recreating diverse techniques [5, 6].

This comprehensive approach not only improves technical dexterity, but simulation also shortens learning curves, enabling repetitive training focused on specific tasks in a safe and controlled environment, and therefore, without risks to patient health [7].

In this study, an inorganic model of a 3D-printed laparoscopic supramesocolic simulator for Roux-en-Y bihepatic-jejunostomy is developed. This model allows replicating the surgical technique of said procedure and facilitates the acquisition of complex skills and abilities required to carry out the practical sessions, providing an additional tool for future decision-making and training for surgeons-in-training.

MATERIALS AND METHODS

This is a prospective and longitudinal study involving training sessions conducted by a fourth-year resident from the General Surgery specialization program of the Universidad Central de Venezuela, based at the Hospital Universitario de Caracas, within the Cátedra de Clínica y Terapéutica Quirúrgica "B". Twenty practical sessions were performed using the proposed laparoscopic training model, supervised by three expert surgeons in advanced laparoscopy.

Upon completion of the 20 practices, performance was evaluated by cross-referencing execution time with the GOALS scale score for each practical session, which were recorded via video and archived in a digital registry. Each session was evaluated by three expert surgeons. Furthermore, upon completing all practices, a Likert satisfaction scale was administered to the participant.

Absolute and relative frequencies were calculated for qualitative and quantitative variables as deemed necessary. Additionally, linear trend charts were generated to analyze the directionality of the ordinal variables to be associated.

For statistical analysis, SPSS 26 software (IBM, Chicago, USA) was utilized, applying the non-parametric Kendall's Tau-B statistical test, considering results as statistically significant when $p < 0.05$ and highly significant when $p < 0.01$.

Procedure

For the execution of this project, a second-version supramesocolic model will be used, which allowed the replication of previously established structures, pre-designed and printed using 3D technology (Figure No. 1). The model consists of 27 pieces, including a flat base upon which supramesocolic structures are arranged, such as the stomach, duodenum, and accessory biliary tract, as well as the right and left hepatic ducts, the main bile duct, and the portal system. For the main bile duct, a 9-cm long support channel is provided for hybrid components (10-mm diameter rubber tubes). Similarly, a support channel is available for 10-mm diameter rubber tubes representing the portal venous system. The fixation of components was achieved using pins at each end of the channels. This features a modification from the initial model, as it provides removable pieces in the biliary tract, allowing the procedure to be performed on the hepatic ducts, resulting in a bilateral end-to-side anastomosis. This procedure will be conducted in a laparoscopic box trainer that simulates the abdominal cavity, located in the laparoscopic training unit of the Cátedra de Clínica Quirúrgica y Terapéutica "B", Servicio de Cirugía II at the Hospital Universitario de Caracas, where a bihepatic-jejunostomy will be recreated. In each practical session, two 5-mm trocars will be placed, through which laparoscopic instruments will be introduced into the box trainer. An atraumatic grasper, a Maryland dissector, a needle driver, and laparoscopic scissors will be used to perform the following phases:

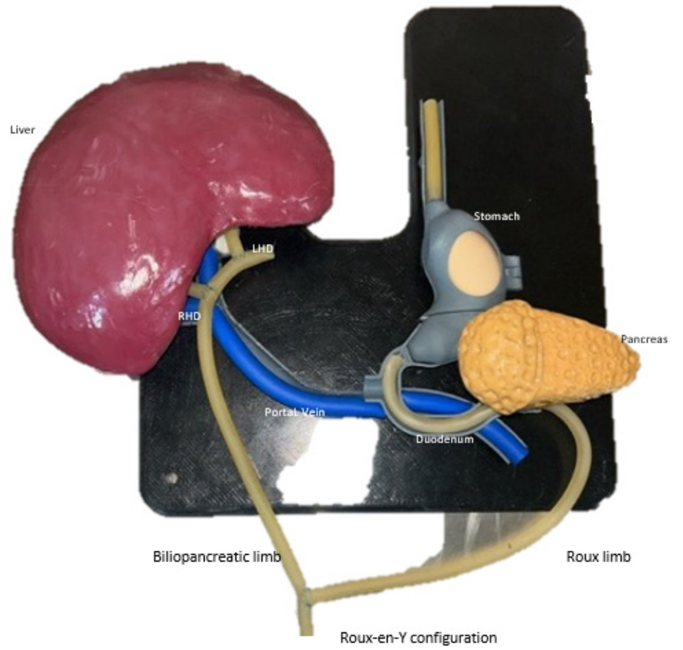

Figure 1. 3D-printed supramesocolic anatomical model.

Phase 1: Bihepatic-jejunostomy

- Visualization of the hilar plate and both hepatic ducts on the model.
- Initially, the site on the jejunum is selected and divided using laparoscopic scissors; the biliary limb is ascended 20 cm from the ligament of Treitz, and the distal end of this loop is closed using a simple continuous suture (4 throws) with 4-0 monofilament suture on an RB-1 needle (Figure No. 2).
- Selection of the anastomosis site for each hepatic duct and creation of an enterotomy of approximately 1 cm in the biliary limb of the intestine using laparoscopic scissors.
- The left hepatic duct anastomosis is initiated using 4-0 monofilament suture on an RB-1 needle, beginning on the posterior wall from left to right. The needle is passed through the left corner of the lumen of the tourniquet representing the intestine from inside to outside, and through the left corner of the tourniquet representing the left hepatic duct from outside to inside, followed by knotting with three throws positioned on the internal aspect. Four continuous throws are passed along the posterior wall to the right corner of the anastomosis, where three knots are tied, remaining inside the anastomosis (Figure No. 2).
- Using a new 4-0 monofilament RB-1 suture, the anterior wall of the left hepatic anastomosis is initiated from the right corner from right to left. The needle is passed through the corner of the lumen of the tourniquet representing the intestine from inside to outside, and through the right corner of the tourniquet representing the left hepatic duct from outside to inside, followed by three throws that will remain on the internal aspect. Four continuous throws are continued

along the anterior wall to the left corner, terminating with three knots placed on the external aspect of the anastomosis (Figure No. 2).

- The anastomosis procedure is repeated for the right hepatic duct (Figure No. 2).

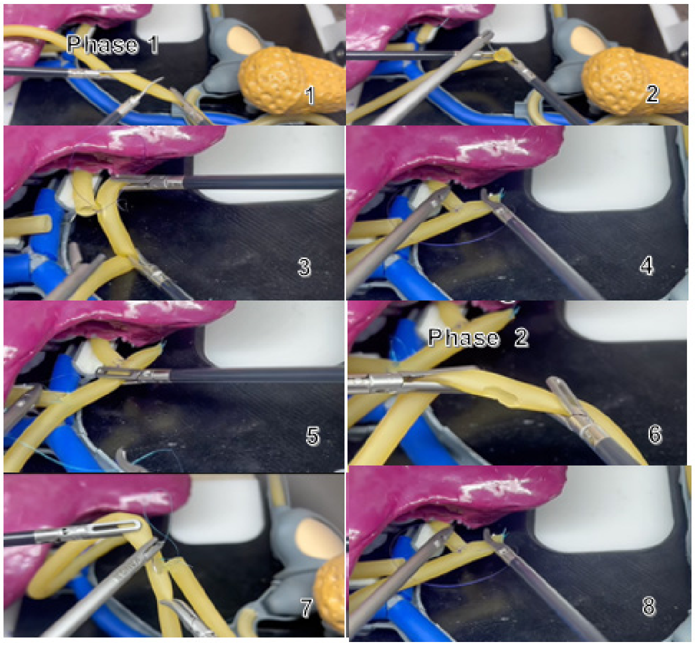

Figure 2. Operative phases and technical steps of the laparoscopic bihepatic-jejunostomy.

Phase 2: Entero-enterostomy

Roux-en-Y: At 15 cm from the fixed loop, the end-to-side anastomosis is constructed. A 7-mm enterotomy is made in the biliary limb. The anastomosis begins at the superior corner; the needle is passed from inside to outside through the superior corner of the tourniquet simulating the alimentary limb at the ligament of Treitz on the right, and subsequently from outside to inside through the superior corner of the biliary limb on the left using 4-0 monofilament suture with an RB-1 needle. Knotting is performed with 3 knots remaining on the internal side, with the assistance of an assistant who approximates the alimentary limb to the biliary limb. This is followed by 4 internal throws along the posterior wall, ending at the inferior corner with three knots tied inside the entero-enterostomy. The anterior wall is continued from bottom to top using a new 4-0 monofilament suture with an RB-1 needle, anchoring a stitch at the inferior corner. It continues from inside to outside of the biliary limb on the left, and then from outside to inside on the alimentary limb on the right, performing the knotting with 3 knots remaining on the internal aspect of the inferior corner. Four continuous throws are continued along the anterior wall to the superior corner, securing the suture with 3 knots on the external aspect, thereby completing the anastomosis (Figure No. 2). End of exercise.

RESULTS

Twenty practical sessions were carried out in a laparoscopic black box with the Roux-en-Y bihepato-jejuno anastomosis model. The data was collected in an Excel format, where the results of the GOALS scales for both the bihepatic-jejunostomy and the entero-enterostomy were compiled.

Regarding the GOALS scale scores for the bihepatic-jejunostomy, initial scores in the first practices ranged between 13 and 15 points; increasing between practices 5 and 6 to 17 points; followed by 3 sessions with 19 points; and maintaining 21 points between practices 10 and 18. Finally, in practices 19 and 20, scores of 23 and 25 points were observed, respectively (Figure No. 3).

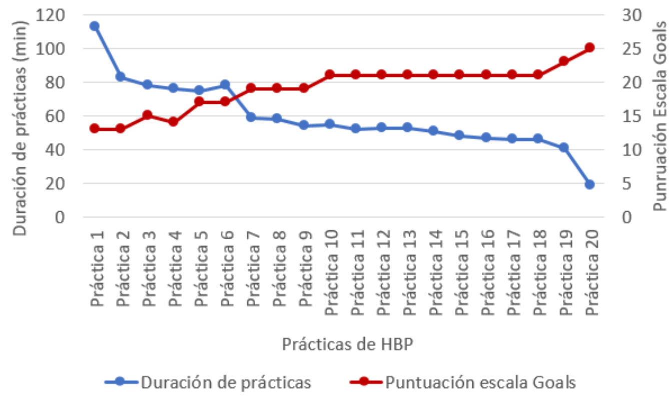

Figure 3. Technical learning curve demonstrating procedural duration trends and corresponding Global Operative Assessment of Laparoscopic Skills (GOALS) scores across the chronological sequence of bihepatic-jejunostomy training sessions.

For the entero-enterostomy, the initial scores obtained via the GOALS scale ranged between 15 and 17 points; increasing to 19 points in practice 7; while from practices 8 to 17, the score remained at 21 points. In practices 18 and 19, the score rose to 23 points, and the maximum score was achieved in the final practice (Figure No. 4).

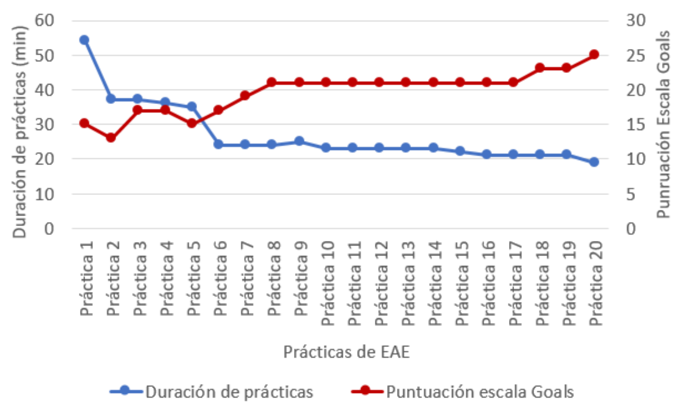

Figure 4. Technical learning curve demonstrating procedural duration trends and corresponding Global Operative Assessment of Laparoscopic Skills (GOALS) scores across the chronological sequence of entero-enterostomy (EEA) training sessions.

Regarding surgical time, a shorter execution time was observed as the practices progressed for the bihepatic-jejunostomy. The first practice was completed in 113 minutes, which progressively decreased until the tenth practice, executed in 55 minutes, and continued to decline until the end of the sessions, where the last practice was completed in 19 minutes. When comparing surgical times between the bihepatic-jejunostomy and the entero-enterostomy, it is observed that as practices progressed—disregarding isolated spikes—there was a clear downward trend in time across the training sessions (Figure No. 5).

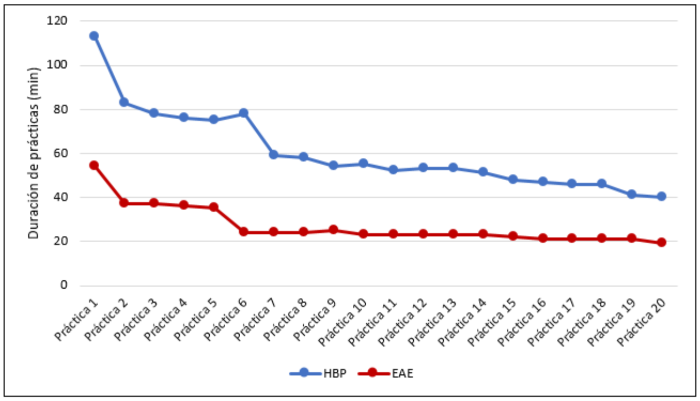

Figure 5. Comparative surgical efficiency curve demonstrating total operative time minimization across sequential training sessions for both the bihepatic-jejunostomy and the entero-enterostomy components.

An asymptotic curve was observed between the duration of the bihepatic-jejunostomy and the score obtained via the GOALS scale (tau-B = -0.790), demonstrating a clear cutoff point at practice number 7 (Figure No. 3). Similarly, the relationship between the duration of the entero-enterostomy and the score obtained through the GOALS scale exhibited a comparable behavior, achieving a cross-variable intersection at practical session number 5 for this procedure (tau-B = -0.786) (Figure No. 4).

DISCUSSION

Laparoscopic surgery currently represents a revolution in surgical practice for complex procedures. The use of training models offers a solution for training surgeons facing these complex operations. Consistent with the literature, our 3D-printed supramesocolic model provides ideal conditions for acquiring surgical skills and dexterity to recreate all steps of a Roux-en-Y bihepatic-jejunostomy. This aligns with [8], who utilized 3D simulation models to successfully recreate esophagogastric procedures within the field of minimally invasive surgery, positively influencing the learning curve of the surgeon-in-training and allowing them to acquire skills and dexterity prior to performing these complex operations on humans.

In the described 3D supramesocolic simulation model, a bihepatic-jejunostomy with Roux-en-Y reconstruction was successfully recreated using high-technology components that supported procedural development. This allowed for the objective measurement of acquired technical skills and dexterity through tools like the GOALS scale [9-10].

Kwon C.I. et al. [7] developed a 3D-printed ERCP simulation model that proved to be economical, eco-friendly, durable, and easy to manufacture, allowing users to reproduce multiple procedures on said model, as was observed in the present research.

The practical sessions conducted with the presented model demonstrated an upward trend in scores, showing continuous improvement in skill acquisition and execution times. Execution time was inversely proportional to the number of completed practices, allowing these metrics to be effectively measured and evaluated, as repeating the exercise with the 3D model enables the refinement of the surgical skills of the training surgeon.

Furthermore, as shown by Rubín A. and Vassallo M. [11], the progression of laparoscopic skills was demonstrated through GOALS scale scores awarded by expert surgeons, revealing how scores successively increased in the present study as the number of practices advanced [12].

Several advantages can be highlighted regarding the inherent tissue characteristics of this 3D simulation model, providing the necessary tactile resistance similar to what would be encountered in the actual tissue of a patient undergoing a bihepatic-jejunostomy. Moreover, the 3D supramesocolic model is versatile and can be employed to develop other surgical procedures [12].

While the 3D model does not allow for the reproduction of certain intraoperative events, such as hemorrhage, or the verification of anastomotic integrity, it nonetheless constitutes a fundamental tool for developing laparoscopic skills. Additionally, it is characterized by being low-cost, highly reproducible, and, unlike live animal models, it requires neither specialized personnel nor a fully equipped laboratory facility for its application [12].

CONCLUSIONS

Se consiguió elaborar un modelo supramesocólico impreso en 3D que recreó de manera bastante precisa los pasos para bihepático-yeyuno anastomosis en Y de Roux. El uso del modelo permitió analizar las habilidades y destrezas quirúrgicas aplicando la escala GOALS, en la medida que progresaban las prácticas lo que a su vez se tradujo en la adquisición de habilidades básicas necesarias para la realización de cualquier procedimiento laparoscópico. El uso del modelo demostró reducción del tiempo en un operador sin experiencia previa en dicho procedimiento. De acuerdo al grado de satisfacción, se determinó que el modelo posee un nivel de fidelidad aceptable para la ejecución de la BH-Y - A en Y de Roux, por lo que su utilización brindaría la base para implementar prácticas de otros procedimientos biliodigestivos. El modelo además de permitir adquirir las habilidades y destrezas laparoscópicas, demostró ser reproducible, portátil, de bajo costo, transferible y ecológico.

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Conflict of Interest

The authors declare that they have no competing or conflicts of interest.

Ethical Considerations

Protection of human subjects and animals: The authors declare that no human or animal experimentation was conducted for this research.

Confidentiality, informed consent, and ethical approval: This study does not involve personal patient data nor does it require ethical committee approval. SAGER guidelines are not applicable.

Declaration on the use of artificial intelligence: The authors declare that no generative artificial intelligence was utilized for the drafting of this manuscript.

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