Oviedo-Peñata *et al. BMC Veterinary Research* (2025) 21:64
https://doi.org/10.1186/s12917-024-04463-4

BMC Veterinary Research

RESEARCH Open Access

Training total laparoscopic gastropexy using a composed simulator and evaluating the significant transfer of surgical skills performed in growing pigs in vivo

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Abstract

Background An advanced curriculum for training Total Laparoscopic Gastropexy (TLG) was developed using the CVLTS-composed simulator based on an ergonomic model of a canine abdominal cavity. The performance of Veterinary surgeons trained in basic laparoscopic surgical skills during 15 training TLG sessions (experimental group, $n=10$) was compared to the TLG performance of veterinary surgeons with intermediate ($n=10$) or advanced ($n=6$) laparoscopic skills. The transfer of surgical skills to a live model was assessed by performing TLG in fattening pigs under operating room conditions using barbed sutures. Experimental group performance after accomplishing the TLG training curriculum and all groups' performance during TLG in the in vivo model were videotaped and evaluated by external Minimally Invasive Surgery (MIS) experts using the GOALS and TLG-specific ranking (SRS) scales. Also, a quantitative assessment comprising time, smoothness of movements, and angular displacement using a Hand Movement Assessment System (HMAS) was performed. Besides, a postmortem biopsy recovered from the gastropexy site three months after surgery to evaluate gross and microscopic characteristics by histopathology was analyzed.

Results GOALS and SRS scores ($P<0.05$), and time, smoothness of movements, and angular displacement during TLG ($P<0.01$) significantly improved in the Experimental group after training. They also compared their performance with expert and intermediate groups ($P<0.05$) performances. The learning curve for intracorporeal suture stabilized since the tenth (out of 15) training session. Besides, trainees achieved significant TLG skills' in vivo transfer, with no significant difference from the intermediate and expert group performances. The presence of mature collagen (100% of cases), cartilage and bone metaplasia, and foreign body reaction (25% of cases) were found at histopathology evaluation of the gastropexy site, evidencing normal healing.

Conclusion The TLG training curriculum supported the acquisition of TLG surgical skills in the training box and their transfer to the in vivo model. The experimental group's TLG performance in vivo did not significantly differ from the intermediate and expert groups. The clinical outcome and histopathological findings evidenced complete gastropexy-site healing.

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Keywords GOALS, MIS, Simulation training, TLG, Training schedule, Training programs, Veterinary surgery

Background

Minimally invasive surgery (MIS) performance requires previous training in specific surgical skills compared to conventional surgery [1, 2]. Therefore, MIS training requires a learning curve developed in a simulated environment, avoiding risks to the trainee and the patient. The objective of the simulation curriculum is to allow novices' feedback and evaluation while replicating intervention scenarios of actual patients [3]. Despite the availability of validated simulators for training basic [4–6] and advanced laparoscopic skills [7–12] in veterinary surgery, research is still needed in curriculum development to determine the best methods of laparoscopic skills training [13–16]. Authors have defined that 2 to 12 training sessions are required to acquire basic laparoscopic skills [17, 18] and obtain reliable training performance data [9, 10, 19]. Only a few reports evaluated the transfer of surgical skills from a simulated environment to a real surgical environment [20]. Intracorporeal suturing is an advanced surgical skill required for successful MIS performance and one of the most difficult to achieve [21, 22]. Therefore, it must be practiced on a simulator before being performed on patients to reduce surgical risks, surgical time, and operating room (OR) costs [23]. Acquiring the ability to perform intracorporeal sutures allows MIS surgeons to be more versatile when performing total laparoscopic surgery [24]. However, reliable surgical protocols for prophylactic gastropexy and laparoscopic techniques [17, 18, 25, 26] are gaining acceptance among dog owners whose breeds are at higher risk for gastric dilatation-volvulus (GDV). However, this procedure requires special MIS equipment and extensive surgical experience [25, 27]. Currently, total laparoscopic intracorporeal suture gastropexy (TLG) has several advantages over the laparoscopy-assisted technique, including lower impact on postoperative recovery, especially in 30 kg dogs [25], and reduced postoperative inflammation and infection near the gastropexy site [28, 29]. With the working hypothesis that the advanced laparoscopic training program for laparoscopic gastropexy in the CVLT simulator [30] using ex vivo pig stomach could confer significant transfer of surgical skills when operating in the real MIS surgical environment, the objective of this study was to evaluate the substantial transfer in surgical skills obtained by veterinary surgeons with no experience in veterinary laparoscopy surgery after completing an advanced laparoscopic training program to perform TLG. The training program consisted of 15 sessions, each lasting [4.5 months on average] and covering [specific skills or techniques].

Methods

Type of study and approval of Institutional board on human or animal subjects' research type study.

The Bioethics Committee for Research on Human Subjects CBE-SIU and the Ethics Committee for Animal Experimentation from the University of Antioquia approved the study. All participants enrolled in the study signed written informed consent forms before participating. The experimental Phase performed on the simulator was conducted in the School of Veterinary Medicine, Faculty of Agricultural Sciences, University of Antioquia (Medellín, Colombia). The experimental Phase on the live pig model was conducted at a private practice (Velodromo Veterinary Hospital Caninos y Felinos, Medellín, Colombia). The pigs were obtained from the University of Antioquia pig facility. Once they were intervened, they were delivered to a private producer who accepted the pigs as donations and who gave the guarantee to take the samples in sanitary conditions once the animals were slaughtered. They were not euthanized as part of the experiment protocol. The pigs were brought to slaughter at the end of their finishing period.

Phase 1: advanced laparoscope training program for TLG using a composed simulator

The experimental curriculum was evaluated in (i) veterinarians pre-trained in basic laparoscopic surgery skills in the CVLTS simulator [26] who voluntarily accepted participation in training total laparoscopic gastropexy with intracorporeal suture (TLG) (experimental group, $n = 10$). The sample size was chosen for convenience, considering they had participated in a previous study to validate the CVTLS simulator for training basic laparoscopic skills [26]. (ii) Veterinarians with experience in minimally invasive surgery (MIS) who performed several laparoscopic techniques, including laparoscopic-assisted gastropexy, but not TLG (intermediate group, $n = 10$). (iii) Veterinary surgeons performing TLG in dogs are leading surgeons for the entire TLG procedure, with a minimum of 3 years of experience and more than 30 MIS procedures [40, 44] (expert group, $n = 6$). Participants completed a questionnaire with demographic information, including age, sex, laterality or hand dominance preference, and years of MIS experience. Experience in MIS, simulated laparoscopic training, and video games were assessed through a visual analog scale (VAS) from 0 mm to 100 mm defined as follows: for MIS level of experience, 0 mm indicated no experience at all, 50 mm indicated the surgeon had performed a minimum of 10 procedures as the leading surgeon, and 100 mm displayed board certified specialist weekly performing a variety of MIS procedures over the past three years. For experience in the use of simulators before MIS training: 0 mm indicated they had never conducted simulator training, 50 mm indicated they had occasionally used simulators, including short representative courses or commercial samples, and 100 mm indicated they had received rigorous training under a valid and structured curriculum plan, with weekly repetitions for weeks or months. Finally, assessing video game experience, 0 mm indicated they had never played any video games, and 50 mm indicated they had occasionally played video games in the last three years or played video games regularly (from 0 to 3 h per week during more than a year) more than five years ago, but not in the last five years, 100 mm indicated had played video games daily to weekly in the previous three years or for more than three hours per week for a minimum of eight years.

Initial assessment (IA) before starting the training program

The experimental group was instructed through an expert class on performing TLG with a double intracorporeal suture before entering the advanced laparoscopic training program. Also, they read the written instructions and watched a video about the training TLG protocol. Subsequently, their TLG performance was evaluated on the CALMA veterinary lap-trainer simulator (CVLTS) using ex vivo pig stomachs obtained postmortem at the slaughtering plant. Each participant's surgical skills were videotaped and double-masked evaluated by three expert MIS trainers using two 5-point Likert-type scales: The Global Operative Assessment of Laparoscopic Skills (GOALS) rating scale and a procedure-specific rating scale (SRS) for TLG previously validated for the procedure. This data determined interrater reliability using the intraclass correlation coefficient (ICC, 0–1). In addition, manual dexterity was assessed with a hands movement assessment system (HMAS) using motion tracking sensors (inertial motion units - IMUs) affixed on the back of each hand, which allowed the quantification of the following metrics: surgical time (sec), number of movements, the smoothness in the movements (abruptness) and angular displacement [30]. Once the evaluation was completed, technical errors such as mucosal permeability and suture line untying were also evaluated by direct stomach visualization. Each participant had a maximum of two hours to complete the TLG. The test was finished if participants exceeded this time or gave up on the following exercises. Participants could adjust the simulator position according to height, and the monitor was adapted to their eye level on demand.

After finishing the theoretical session, the advisory was provided to any participant who doubted the TLG procedure. Participants could handle instruments outside the training simulator for five minutes to become familiar with laparoscopic instruments. Warm-up exercises were not allowed immediately before the tests, and no feedback was given once the trial began. The intermediate and expert groups performed the TLG procedure and were evaluated under the same conditions as indicated for the experimental group. These groups still need to complete the training sessions.

Training sessions

After the IA, the experimental group started a 15-session training program that considered critical aspects such as theoretical sessions, deliberate practice, sequence steps, and progressive, cumulative experience [3, 31, 32]. Each session was scheduled and conducted under the supervision of the principal researcher, responsible for delivering feedback to each participant during training. The TLG technique was organized into four basic exercises (Fig. 1), including:

Anchoring exercise

(corresponding to training sessions 1 to 3) comprised suturing the stomach tothe abdominal wall using a non-absorbable polyamide monofilament suture u.s.p. 2 – 0, 75 cm long with a 35 mm needle with a 3/8-circle cutting tip. The suture was passed percutaneously through the siliconized skin at the gastropexy site located 2 to 3 cm caudal to the last rib and 5 to 8 cm lateral to the midline. The needle was fixed inside the cavity with a laparoscopic needle holder and passed through the entire thickness of the antrum of the ex vivo pig stomach. Next, the suture was passed through the abdominal wall adjacent to its anterior entry point. On the outside of the abdominal wall, the ends of the suture were clamped with a Kelly clamp. This maneuver was repeated at 5 to 6 cm between both points. This suture made it possible to mimic the temporary anchoring of the stomach to the abdominal wall during incision and suturing. In addition, the second anchor point reduced stomach tension during the suturing maneuver (Fig. 2. A). The surgeon in charge of the procedure performed five repetitions in each session, and the time elapsed from the time the instruments were in position until the last anchor point was completed was recorded.

Cutting exercise

(corresponding to training sessions 4 to 6) consisted of the incision of the serous-muscular layer of the stomach 4 to 5 cm long. This exercise was performed on the ex vivo pig stomach with laparoscopic Metzenbaum scissors. The incision of the stomach seromuscular layer was attached to the silicone patch of the simulator that mimics the abdominal wall. This incision is parallel to the last rib (Fig. 2B). The participant had to repeat the above exercise four times in each session. The duration was

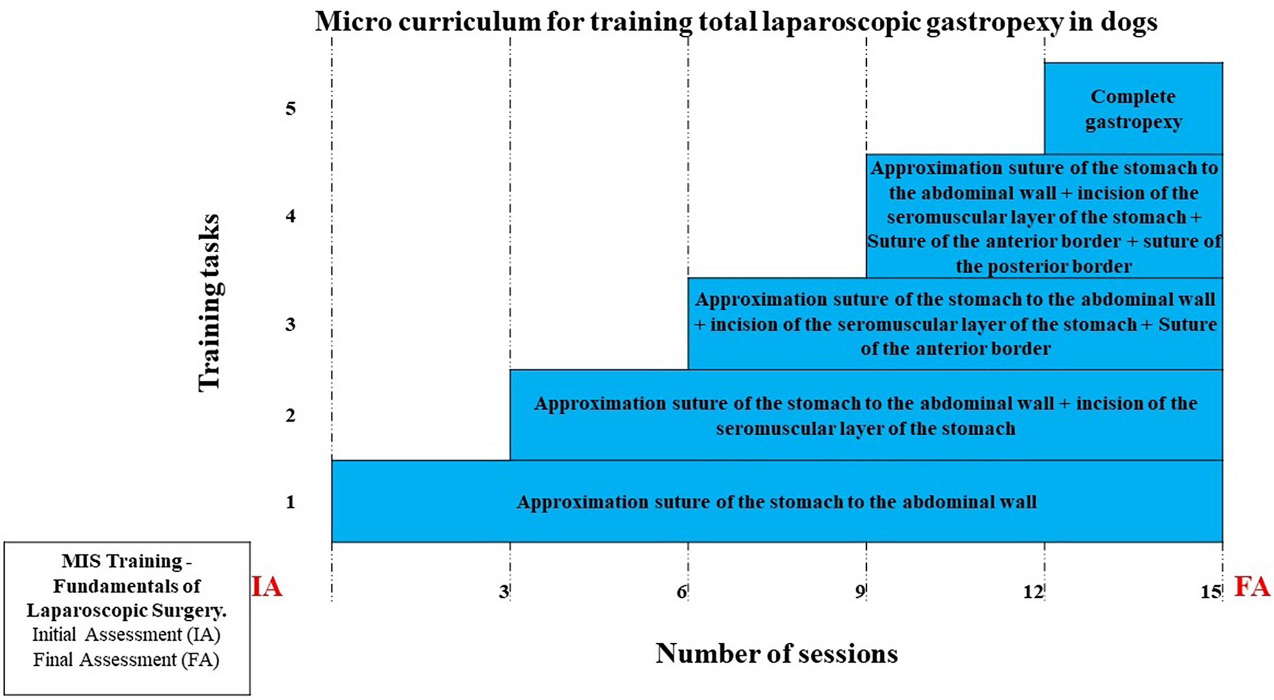

Fig. 1 The curriculum of the advanced training program

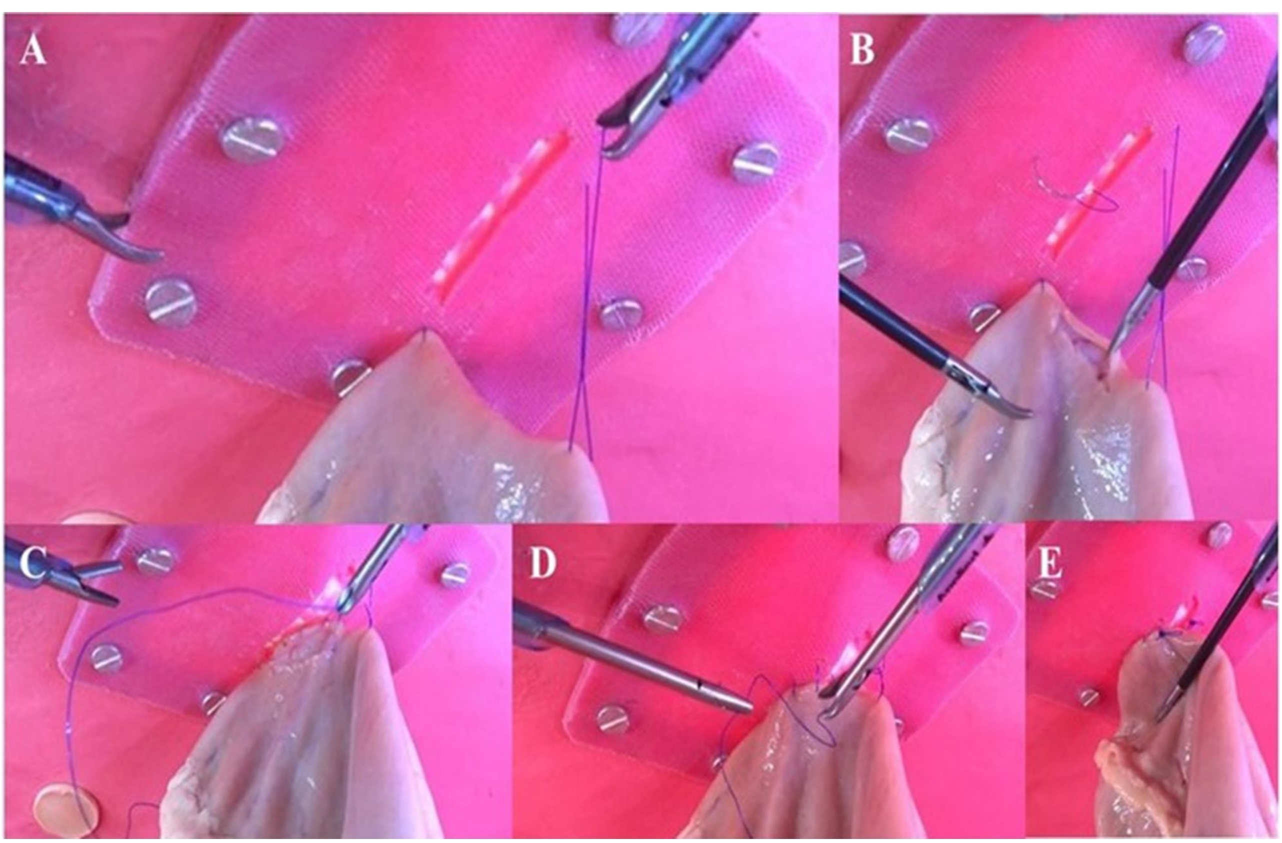

Fig. 2 Internal images of the CALMA Veterinary Lap-trainer Simulator (CVLTS) **A**. Anchorage, **B** cut, **C**. Suture of the lateral side, **D**. Suture of the medial side. **E**. Gastropexy completed

recorded from the introduction of the scissors until the last cut was made on the stomach's seromuscular layer.

Suturing exercises

(corresponding to cranial and caudal borders suturing). Suturing was performed using a non-absorbable polyamide monofilament suture u.s.p. 2 – 0, 19 cm long with a 25 mm needle with a ½-circle round tip using a simple continuous pattern. The needle was introduced into the simulator through the silicone skin adjacent to the gastropexy site, mimicking the percutaneous passage of the needle. First, the seromuscular layer cranial border of the stomach antrum was sutured with the lateral edge of the silicone skin incision (Fig. 2C). Once the previous exercise was completed, the second piece of suture was introduced, the caudal margin was sutured to complete the gastropexy (Fig. 2. D and E), and the exceeding suture was removed from the simulator. The experimental group repeated the cranial suturing four times in each session (training sessions 7 to 9), and the time spent on each suture was recorded. The caudal suture exercises were repeated three times in each session, during which time expended was also recorded (training sessions 10 to 12). Performing complete TLG comprised the last three sessions (training sessions 13 to 15), during which time expended was also recorded. All suture sessions were conducted with a reusable laparoscopic needle holder with a curved type V-style handle and a contra needle holder.

Final assessment (FA) after completion of the training program

After completing the training program, all the experimental group participants were evaluated under the same standards of IA. In addition, data were compared with data from intermediate and expert groups.

Phase 2: performance of TLG in live-growing pigs using barbed suture

Upon completion of the CVLTS training, participants in the experimental group were required to receive a master's class from studying and learning how to perform a live TLG using a bearded suture (V-Loc™ 180® Covidien, u.s.p. 2 – 0 with GS-22 round needle, 27 mm 1/2 Circle, VLOCL2105.), according to the modified technique by Mayhew and Brown (2009) [25]. In addition, a step-by-step instructional video guide describing the entire procedure was provided. In the TLG, the cutting line had to be cauterized with a monopolar electrosurgical knife connected to the Metzenbaum scissors. The bearded suture had to include the four edges of the two incisions (Fig. 3C-F). Participants practiced a complete session on the CVLTS before performing in vivo surgery. Experimental group trainees were evaluated using the same formats and tools in Phase 1 on the simulator, but now on a live patient under operating room conditions. As previously mentioned, three MIS experts sent video records evaluation under double-blind mode for surgical performance assessment using GOALS and SRS scales. Data from the experimental group were compared with data from the expert group that performed TLG in vivo with no previous training, as did the experimental group.

Protocol for performing live TLG

Anesthesia plan

The pigs were premedicated and anesthetized under a standardized anesthetic and analgesic protocol established by the Hospital Veterinario Velódromo Caninos y Felinos (Medellín, Colombia). Premedication consisted of a combination of ketamine (10 mg/kg; i.v.), xylazine (1.5 mg/kg; i.v.), and atropine (0.05 mg/kg; i.v.), ketoprofen (2.2 mg/kg; i.m) for analgesia and then at 24-hour intervals for three postoperative days. In addition, 1.5 ml penicillin G sodium and procaine (20,000 IU/ml) + spiramycin sulfate (20 mg/kg; i.m) as preoperative prophylaxis at premedication, and then every 24 h after that for five days. For induction, it was used a combination of propofol (2 mg/kg; i.v), fentanyl (2ug/kg; i.v), and dexamethasone (0.3 mg/kg) was used. In addition, 2% isoflurane and 1.5 L/min oxygen flow through an anesthetic machine were used for anesthesia maintenance. Additionally, 0.2 mg/kg ondansetron was administered by i.v. infusion. During recovery, 0.05 mg/kg yohimbine diluted in SSF was applied slowly by i.v. injection. All patients recovered with 1 L/min oxygen support, and safe extubating was only performed when each pig exhibited palpebral reflex, swallowing, and standard ventilatory mechanics. Postoperative cures were performed for 14 days with the local application of a healing cream based on zinc oxide, pine oil, and carbolic acid directly on three laparoscopic incisions.

Surgical procedure

Twelve fattening pigs of approximately 30 kg (Camborough C29, PIC Colombia genetics, Medellín, Colombia) bred on the University of Antioquia pig farm were used for the TLG. Before starting the TLG, the surgeon was positioned on the left side of the pig, and the laparoscopy tower was just in front of the right side. With the anesthetized pig in dorsal decubitus, a first portal was placed using a modified Hasson technique. Then, to set the first 11 mm portal (Kii Fios, Applied Medical, CA, USA) for lens positioning, a ventral midline incision was made 3 cm supraumbilical, trying to leave the falciform ligament on the left side. The abdomen was inflated with CO_2 to achieve 8 to 10 mmHg pressure using a pressure-regulating mechanical insufflator (Stryker, MI, USA). A 10 mm, 30° laparoscope (Stryker, MI, USA) was

Fig. 3 **A**. External positioning of the portals (green) on the live porcine model. The right costal margin and xiphoid cartilage (blue) are shown. The red line shows the layout of the incision and the final gastropexy. **B**. Anchoring the pyloric antrum to the abdominal wall with a percutaneous suture. **C**. Cauterization and cutting of the stomach and abdominal wall seromuscular walls of approximately 4 cm. **D**. Continuous stitch clockwise (right-hand verse) until five loops were completed. **E**. Completion of the five passes, the barbed suture is locked. **F**. cut the barbed suture after changing the direction of the suture pattern

inserted into the peritoneal cavity. Under direct vision, one 11 mm portal (Kii Fios, Applied Medical, CA, USA) was placed 3 cm caudal to the xiphoid process above the alba line. Two 5 mm portals were set 2 cm infra umbilically and located on the right paramedian region. The principal researcher performed the ports and pig positioning. If the stomach antrum were not immediately visible until obtaining an adequate view to perform the anchoring suture, the experimental and expert group surgeons could manipulate the laparoscopic atraumatic grasping forceps (5 mm x 330 mm) inside the abdominal cavity. The anchorage was made 2 to 3 cm caudal to the last rib and 5 to 8 cm lateral to the midline, considering the ideal position to perform the gastropexy with a non-absorbable monofilament polyamide (nylon) u.s.p. 2 – 0 of 75 cm length, and 3/8 circle 35 mm needle with a cutting tip. It was passed percutaneously near the pyloric antrum between the greater and lesser curvature of the stomach. Before cutting, a 3 to 4-cm linear cauterization of the seromuscular layers of the stomach and coastal peritoneum was performed (Fig. 3C and D). Subsequently, a partial incision was made in both layers up to the transverse muscle in the abdominal wall using laparoscopic curved Metzenbaum scissors (5 mm x 330 mm).

Through the 5 mm portal, a u.s.p. 2 – 0 barbed suture was introduced with a GS-22 round needle, and a 1/2 circle 27 mm needle (V-Loc™ 180® Covidien VLOCL2105) to linearly suture the transversus abdominis muscle and stomach antral incisions. For this stage, the intracorporeal suture was performed with a reusable laparoscopic needle holder curved type V style handle in the right hand and a laparoscopic curved dissecting forceps (5mmx330mm) in the left hand. The continuous knotless suture line was initiated with a right reverse (counterclockwise) movement of the needle, taking both edges of the abdominal wall incision toward the edges of the stomach incision. The needle was then inserted through a prefabricated loop of the barbed suture to complete the initial knot. Subsequently, five complete loops were made clockwise (right verse), starting from the edges of the stomach towards the edges of the abdominal wall, pulling on each completed turn. Finally, the direction of the barbed suture was reversed to secure it in the tissue. Next, the suture was cut with scissors for material (Fig. 3), and the temporary anchor was removed.

Postoperative follow-up

All pigs have been cared for in the veterinary hospital's recovery area, receiving postoperative monitoring until discharge. After complete recovery, they were moved to a commercial finishing pig operation different from the original farm and were fed and cared for under the farmer's responsibility. The researchers were noticed of slaughtering time by the farmer 24 h before slaughtering and then went to the slaughterhouse for postmortem sampling of the gastropexy site. No intervention of the research group was performed on pigs from post-operatory recovery until their finishing period was completed. Accordingly, the farmer never reported any post-surgical complications.

Surgical performance criteria

The competence criterion for performing the TLG on the live pig model by the experimental group participants was established at a minimum score of 20 out of 25 possible points (equivalent to 80%) on the GOALS and SRS scales [20]. Two metrics were used to assess the acquisition of basic laparoscopic skills in veterinary medicine are MISTELS, complemented by the Fundamentals of Laparoscopic Surgery (FLS), and the Veterinary Assessment of Laparoscopic Skills (VALS) [33]. Other metrics include the widely validated Objective Structured Assessment of Technical Skills (OSATS) scale [34, 35], which consists of a global rating scale (GRS) and a specific rating scale (SRS), a checklist of particular tasks, or the Operational Component Rating Scale (OCRS) [9]. Based on the OSATS guidelines, the Global Operative Assessment of Laparoscopic Skills Scale (GOALS) was designed for minimally invasive procedures [36]. OSATS and MISTELS-type metrics strongly correlate with MIS experience level for evaluating basic veterinary laparoscopic surgical performance [6, 9, 10].

For the set-up of 15-session training TLG, learning strategies derived from the theories of the constructivist method were considered, such as training in partial tasks, which consists of deconstructing a complex task into simpler components (exercises) for its practicing. For this reason, the student must acquire proficiency in individual activities before advancing to a more challenging workout until task completion [31]. This strategy was tested in previous studies on medical students who achieved advanced technical skills in laparoscopic suturing comparable to those of senior residents in a short time [3, 32]. In addition, the effects of 10 practical sessions were evaluated in laparoscopic suturing simulation resulting in novices being able to safely complete ovariectomy in bitches with extra and intracorporeal ligation [37]. The progressive, cumulative learning model has a similar structure since the student builds knowledge about a task (surgical procedure) from a more simple, specific exercise. As he learns it, a new activity is added until he reaches a sequence of basic knowledge that will allow him to develop the task he wants to know [16, 38]. The difference is that the learned exercises are repeated every time another more difficult one is added. In our case, this required the student to continue repeating the first tasks throughout the 15 sessions, reinforcing and consolidating the skills acquired throughout the training. Based on the individual's finite capacity for attention concept described by Gallagher et al. (2005), the construction of the training curriculum allowed the consolidation and automation of the surgical technique during training on the simulator independently of the surgical environment. For this reason, once the experimental group members —without experience in MIS procedures— entered the real surgical environment, they required minimal indications [39]. As a result, they could dedicate less attention to these automated tasks and focus on tasks dependent on surgical function [35]. In addition, other items listed as the formula for a successful laparoscopic skills curriculum were considered, such as the cognitive component with a master class and video delivery, a curriculum with a defined objective to TLG learning assessed pre- and post-training with different methods of determining surgical performance, deliberate practice in distributed sessions with appropriate feedback, and even over-training as reported in other studies [11, 32].

Postoperative follow-up and macroscopic and microscopic findings at the gastropexy site

All operated animals were fed a commercial concentrated finishing formula (Solla SA, Medellín, Colombia). Upon they reached the slaughter age (at least 100 kg live weight), they were sent to the slaughterhouse (Frigoporcinos Bello S.A.S. Antioquia, Colombia), which holds official authorization issued by the National Institute for Food and Drug Surveillance (INVIMA, Colombian Government). No intervention by the research group was performed on pigs from post-operatory recovery until their finishing period was completed. Accordingly, the farmer never reported any post-surgical complications. Upon notice by the farmer 24 h before slaughter for next-day postmortem sampling, pigs were subjected to a standard 12-hour fasting procedure, sent to the slaughterhouse the following day, and slaughtered according to the standard method. Then, postmortem samples of the gastropexy site ($n = 9$) were taken at the slaughterhouse.

At the dressing line, the carcasses were checked before eviscerating white viscera, and a photograph of the gastropexy attachment site was taken (Fig. 4). Then, a sample with the stomach serosa fragment attached to the costal parietal peritoneum was taken at the gastropexy site. The samples were transported to the laboratory. Each piece was photographed and evaluated for macroscopic description (Fig. 5).

Sample processing for histopathological examination

The samples were processed in the Laboratory of Animal Pathology, School of Veterinary Medicine, the University of Antioquia (Certified by the technical quality standard NTC-ISO/IEC 17025) by routine histopathology process and staining with Hematoxylin & Eosin (H&E). Briefly, the fragments were processed in kerosene blocks and submitted to the preparation process in Histotechnicon. Then, 5 μm cuts were made, mounted in glass slides, and processed for H&E staining. Finally, the plates were read by a veterinary histopathologist with more than 20 years of experience. This laboratory is certified and conforms to the United States Army Pathology Laboratory standards. The plates were read with an emphasis on the cellular and extracellular matrix elements found.

Statistical analysis

Statistical tests and graphs were run with the statistical environment R v 4.1.2 (2021) under the RStudio v 1.4.1717 (2021) platform. Because no normal distribution of data was found, all variables were evaluated by non-parametrical tests. Accordingly, the Wilcoxon test was only used to compare pre- and post-training assessments within the Experimental group. Comparisons

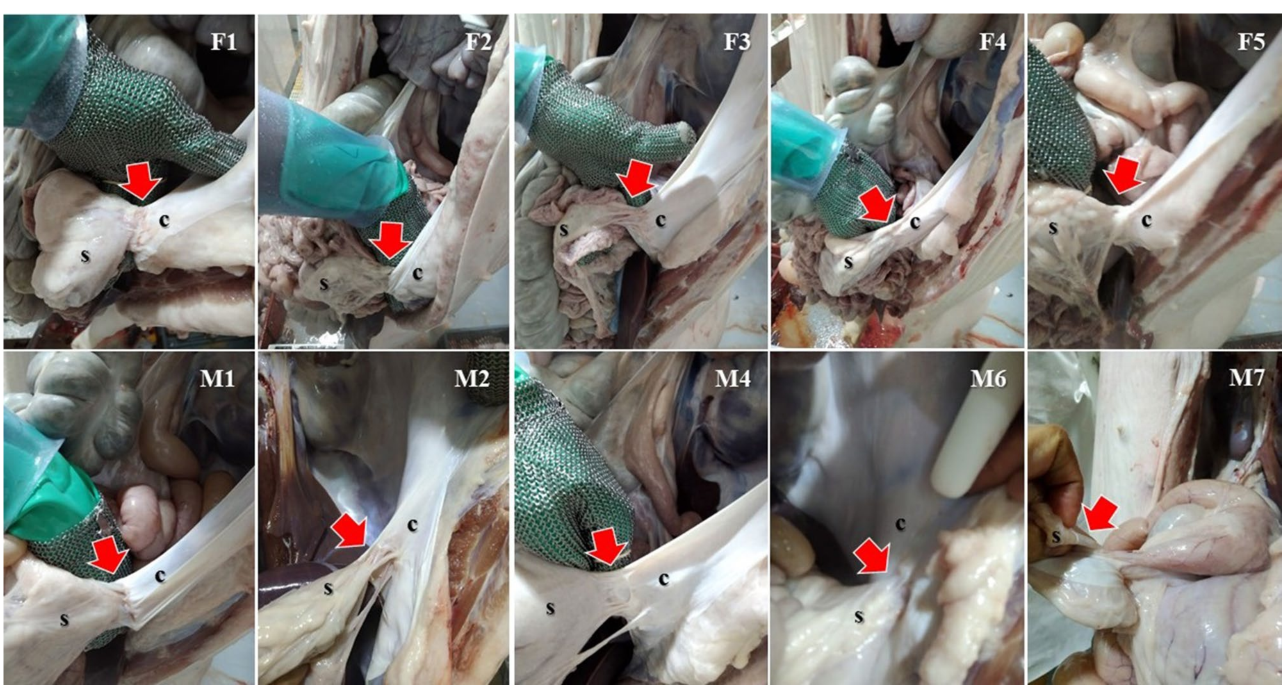

Fig. 4 The macroscopic finding of the gastropexy site at three postoperatively months, immediately after slaughtering females (F1 to F5) and males (M1, M2, M4, M6, and M7), finished pigs. The red arrow indicates the gastropexy site in the carcass. It shows fragments corresponding to the stomach serosa (s) and costal peritoneal (c) sides of the gastropexy

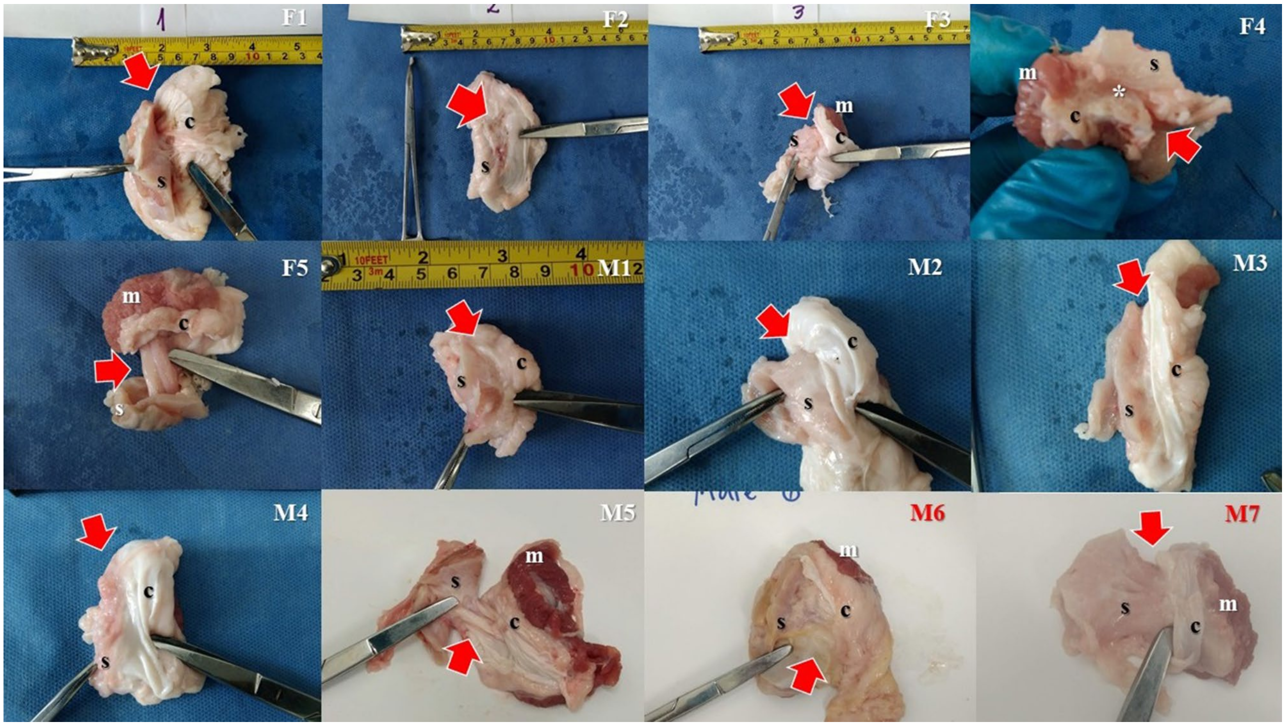

Fig. 5 Macroscopic aspect of gastropexy samples of five females (F1 to F5) and seven males (M1 to M7) before sending for histopathology processing. The red arrow shows the gastropexy site. It is shown fragments corresponding to the stomach serosa (s) and costal peritoneal (c) sides of the gastropexy. In some samples, it is observed that the muscle fragment (m) corresponds to the Rectus abdominal muscle. Macroscopic bone can be observed in female 4 (asterisk)

between Experimental, Intermediate and Expert groups GOALS, SRS, and motion data were compared with the Mann-Whitney U test. The results were expressed as means (min-max). It was considered statistically significant when $p < 0.05$. The Intraclass Correlation Coefficient - ICC was used to evaluate reliability. ICC estimates were calculated using 'irr' package (Gamer et al. 2022) based on a single unit, consistency-agreement, 1-way random model [46]. The association between the demographic variables and the evaluations was determined with the Spearman Correlation Coefficient. The differences in training time within the experimental group (before and after training) and between groups were estimated using regression models. The second derivative of the potential regression curves was used to measure the point where training times stabilized in each exercise. Descriptive statistics were performed for the responses to the satisfaction survey. It was considered statistically significant when $p < 0.05$; correlations between 0.51 and 0.7 were moderate, 0.71 and 0.9 good, and >0.9 very good. Descriptive statistics evaluated the results of the histopathological analysis.

Results

Phase 1: advanced laparoscope training program for TLG using a composed simulator

Initial assessment (IA) before starting the training program

Ten volunteer veterinarian surgeons comprised the experimental group of five women and five men, all right-handed, mean age = 30.5 ± 4.3 years, with a training laparoscopy advanced skills learning course on the CVLTS simulator [27]. The mean VAS score for experiences in MIS, videogames, and simulation ranked between 0 mm and 100 mm, 0 ± 0 mm, 54.7 ± 26.3 mm, and 50 ± 0 mm, respectively. The expert group's mean age was 40.2 ± 4.7 years and consisted of six men with 11.7 ± 6.6 years of MIS experience; all were right-handed, and one participant was ambidextrous. The mean VAS score for experience in MIS, video games, and simulation was 88.5 ± 19.4 mm, 51.3 ± 31.7 mm, and 77.5 ± 24.2 mm, respectively. The intermediate group's mean age of 41.2 ± 8.3 years included nine men and one woman exhibiting 6.3 ± 7.7 years of experience in MIS, all right-handed. The mean VAS score for the experience in MIS, video games, and simulation was 55.6 ± 28.0 mm, 34.0 ± 30.0 mm, and 46.2 ± 8.6 mm, respectively. No statistical difference between the expert and intermediate group for MIS experience and age ($P > 0.05$) was found, but with the experimental group ($P = 0,002$). The experience with the simulators had no statistically significant differences between the experimental and expert groups ($P < 0.05$), but they did with the intermediate group ($P < 0.001$). A statistically significant difference was also found between the experience in MIS declared in years ($P = 0.002$) and the VAS ($P < 0.001$) between the expert and intermediate groups. There were no differences in video game experience between the groups ($P = 0.266$).

Before starting the simulated advanced laparoscopic training program, all experimental group members received instruction from an expert on the protocol to perform TLG on the CVLTS using intra-corporeal suture; subsequently, their performance of this technique was evaluated on the same simulator to obtain baseline surgical performance scores. The results of the metric scores (time, number of movements, smoothness of movements, and angular displacement) measured with a hands movement assessment system (HMAS) and the GOAL scales for evaluating surgical performance are presented in Table 1.

Follow-up and evaluation of training sessions

It required 135 days (4.5 months) to complete the fifteen training sessions of the experimental group. The maximum time per session was 120 min. Under the supervision of the principal investigator, each student recorded their respective time. No variation was observed in the times used for the anchoring, cutting, lateral suture, and medial suture exercises corresponding to sessions 7, 8, 10, and 11, respectively (Fig. 6). Likewise, it was evidenced that during the training, the members of the experimental group only required instructions at the beginning of each task, especially those involving intracorporeal suture, without needing additional instructions.

Final assessment (FA) after completion of the training program

At the end of the fifteen training sessions, the experimental group participants were again evaluated using the same parameters for the initial assessment (IA). Experimental group results comparisons between IA and FA, and with intermediates and experts' performances are shown in Table 1; Fig. 7. The experimental group members significantly enhanced their surgical performance score after training compared to before training, according to GOALS scales mean 13.1 (range 8.3–20), versus 23.5 (range 21.7–25) ($P < 0.05$), respectively; and SRS mean 12 (range 8.3–19.3) versus 22.7 (range 20.3–24.3) ($P < 0.05$), respectively. The surgical performance criterion achieved at the final assessment by the experimental group was 94% and 90.8% for the GOALS and SRS scales, respectively. The experts' scores were 79.6% and 76.8% for the GOALS and SRS scales. The three MIS experts' scoring assessments concordance was good (0.71 to 0.9) for both the GOALS (ICC = 0.818, $P < 0.0001$) and the SRS scales (ICC = 0.71, $P < 0.0001$).

Time and movements' coordination quantitative measurements

Total surgery time, movements, and angular displacement for both hands significantly decreased between the experimental groups comparing IA to FA ($P < 0.05$) except for the cutting exercise. The experimental group performed significantly better than the experts and intermediate groups (Table 1; Fig. 8.). The experimental group's IA GOALS ($P = 0.006$) and SRS ($P = 0.004$) scales were significantly lower compared to the expert group. Metric differences between experimental and expert groups were found only for cutting time ($P < 0.05$) and lateral suture ($P < 0.05$) exercises. Movement smoothness did not significantly differ between groups ($P > 0.05$).

Phase 2: TLG performance in vivo using barbed suture

The experimental group participants found using the barbed suture easier than the conventional non-barbed suture when training TLG on the simulator.

TLG performance in vivo. The experimental group TLG performance in the live porcine model (Fig. 3) was compared with the two experts' performance through the GOALS and SRS scales. All participants completed the TLG in vivo with no principal investigator's assessment. Minor verbal cues were given that did not involve the development of the trained surgical technique to the experimental group participants (e.g., on ergonomics, CO_2 pressure, instruments handling in the abdominal cavity, and steps reassurance). Ten pigs underwent surgery, nine of which were followed up for 90 days. One pig died during the postoperative period in the recovery room due to cardiorespiratory arrest, not interfering with the participants' data collection. The experimental group's mean SRS values (15.7 ± 2.5) were significantly higher compared to the expert (12.3 ± 2.6) group ($P = 0.020$). On the contrary, no statistically significant differences in GOALS scores between the experimental (18.1 ± 3) and the expert (17.5 ± 2.9) groups ($P = 0.737$) were found. The rating concordance given by the external evaluators for in vivo TLG performance was moderate for GOALS (ICC = 0.803, $P = 0.0003$) and suitable for SRS (ICC = 0.646, $P = 0.0067$) scales (Fig. 9), in agreement with the VTLS simulator concordance. Besides, the results of six participants in the experimental group whose surgical performances were evaluated with the HMAS are presented in Table 2.

Table 1 Subjective (GOALS and SRS Scale rating) and objective (time and number of movements) measuremts performed during a training program for advanced laparoscopic gastropexy using the CVLT simulator and post-mortem fresh pig stomach (composed simulator)

Items		[A]Experimental IA (*n* = *10*)	[B]Experimental FA (*n* = *10*)	[C]Expert (*n* = *6*)	[D]Interm (*n* = *10*)	[AB]*p* value	[BC]*p* value	[BD]*p* value	[CD]*p* value
Anchorage	Operating time	422.8 (157–919)	145.8 (105–207)	215 (173–299)	397.2 (211–731)	**0.0019**	**0.0039**	**0.0002**	**0.0196**
	Total movements	365.8 (130–780)	153.9 (102–246)	239.2 (161–329)	391.2 (214–648)	**0.0039**	**0.0047**	**< 0.0001**	**0.0075**
	Smoothness in movements	0.25 (0.23–0.28)	0.287 (0.26–0.32)	0.323 (0.26–0.37)	0.297 (0.24–0.34)	0.1062	0.0793	0.4254	0.2116
	Total angular displacement	10737.1 (3352.3-24019.6)	4823.8 (3064.8-7748.6)	7119.1 (4590.5-10562.3)	12043.6 (6652.6-19342.4)	**0.0039**	0.0727	**< 0.0001**	**0.0312**
Cut	Operating time	234.9 (122–401)	183.6 (49–268)	106.5 (69–166)	199.4 (106–581)	0.2324	0.0559	0.6842	**0.0392**
	Total movements	196.4 (66–375)	201.4 (53–312)	97.8 (53–164)	172.1 (78–537)	0.7695	0.0507	0.5787	0.1179
	Smoothness in movements	0.235 (0.19–0.26)	0.26 (0.21–0.31)	0.292 (0.26–0.33)	0.272 (0.22–0.34)	**0.0142**	0.0898	0.4233	0.3541
	Total angular displacement	4540.7 (1563.6-9518.5)	5086.3 (1042.6-8832.3)	2346.5 (1085.3–3934.0)	4453.7 (1604.2-16751.9)	0.4922	0.1471	0.4359	0.0727
Lateral Suture	Operating time	2058.6 (1321–3193)	650.8 (525–776)	1260.3 (569–1816)	2448.4 (1218–4285)	**0.0019**	**0.0159**	**< 0.0001**	**0.0225**
	Total movements	2066.4 (1153–2937)	742.5 (585–951)	1493.3 (998–2229)	2741.4 (1345–5181)	**0.0019**	**0.0002**	**< 0.0001**	**0.0312**
	Smoothness in movements	0.274 (0.24–0.32)	0.313 (0.26–0.39)	0.373 (0.28–0.43)	0.329 (0.26–0.40)	**0.0299**	**0.0380**	0.3215	0.1139
	Total angular displacement	64139.0 (34137.8-95068.7)	25049.2 (17558.7-34341.3)	49545.9 (21952.9-79007.4)	9351.4 (47020.8-179059.6)	**0.0019**	**0.0109**	**< 0.0001**	0.0727
Middle Suture	Operating time	1808.4 (832–3017)	612.7 (466–754)	981.8 (533–1512)	1966.4 (1173–3848)	**0.0039**	**0.0109**	**< 0.0001**	**0.0159**
	Total movements	1872.3 (773–2807)	692.9 (562–847)	1155.2 (839–1720)	2048.5 (1234–3908)	**0.0039**	**0.0005**	**< 0.0001**	**0.0109**
	Smoothness in movements	0.287 (0.26–0.32)	0.316 (0.25–0.37)	0.377 (0.29–0.47)	0.341 (0.26–0.40	0.0831	**0.0293**	0.1284	0.2102
	Total angular displacement	61837.2 (24911.8-94961.9)	24404.5 (18053.9-30871.7)	40162.1 (20353.5-68510.3)	76833.6 (42818.7-141626.6)	**0.0039**	**0.0419**	**< 0.0001**	**0.0225**
GOALS - GRS (0–25)		13.1 (8.3–20)	23.5 (21.7–25)	19.9 (17.3–24.3)	15.8 (9.7–21.7)	**0.0059**	**0.0192**	**0.0002**	0.0507
SRS (0–25)		12 (8.3–19.3)	22.7 (20.3–24.3)	19.2 (16.3–23.3)	15.5 (9.3–23)	**0.0019**	**0.0124**	**0.0009**	**0.0390**

[AB]*P* value obtained when comparing columns, A (Experimental initial time) and B (Experimental final time) compared using the Wilcoxon Test. [BC, BD, and DC]*P* values were obtained when comparing between Experimental (columns 1 and 2), Expert (Colum 3), and Interendiate (Colum 4) groups by the Mann-Whitney U test. Operating time (Seconds), Total Movements (#), Total Smoothness in movements (#), and Total angular displacement (Degrees). AB comparison performed by the Wilcoxon Test. BC, BD, and CD comparisons evaluated by the Mann-Whitney U Test. GOALS GRS or SRS scores expressed in units from 1 (minimum) to 25 (Maximum). Operating times expressed in seconds, and movements in numbers of movements (Statistically significant differences were established with a P value < 0.05)

Postmortem gastropexy site macroscopic and microscopic findings

Macroscopic findings at the gastropexy site included (Figs. 4 and 5): (i) Firm junction between the seromuscular layer of the stomach and the subcostal parietal peritoneum (samples F1, F3, F4, F5, M1, M2, M3, M4, and M6). (ii) Union through a short pedicle (< 1 cm) (samples M5 and M7). (iii) Union through a long pedicle (> 1 cm) (sample F5). And (iv) Weak connection through a detached pedicle when applying slight traction before recovering the fragment (sample F2).

Histological findings

An expert pathologist (more than 10-year experience) defined arbitrary scores for the absence (score 1), mild (score 2), mild-to-moderate (score 3), moderate (score 4), or moderate-to-severe (score 5) presence of the following microscopic elements assessed at 100X magnification: fibrocytes, hypertrophic fibrocytes, angiogenesis, mature

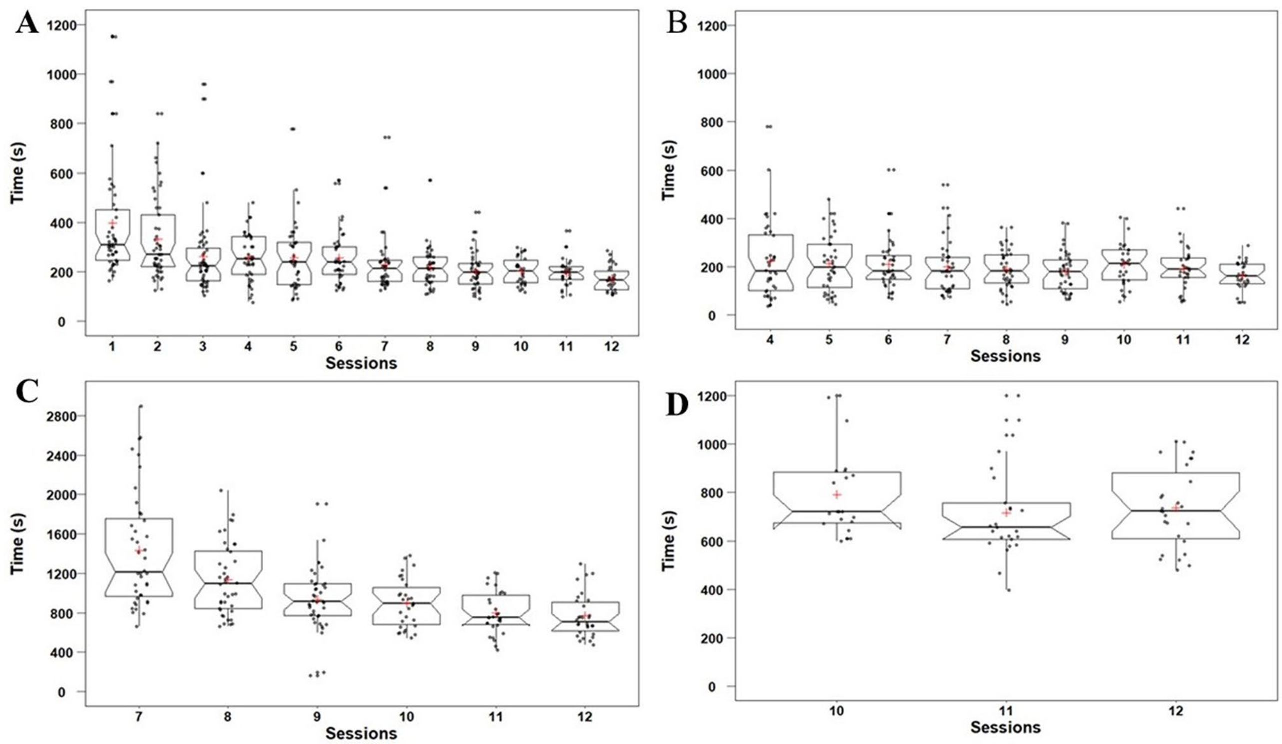

Fig. 6 Notched box and whisker plot of the learning curve according to the time it takes to complete the four tasks: **A**. anchoring, **B**. cutting, **C**. suturing the anterior or lateral aspect, and **D**. suturing the posterior or medial aspect during the training sessions (Figure interpretation: The boundaries of the boxes indicate the central 50% range of the data, with a center line marking the median value. Lines extend from each box to capture the range of the remaining data, with points located beyond the edges of the lines to indicate outliers. Besides, the notches show the most likely expected values for the median. When making a comparison between groups, we can tell if the difference between the medians is statistically significant based on whether their ranges overlap. If any of the notch areas overlap, it is interpreted as no statistically significant difference; if they do not overlap, the difference is interpreted as statistically significant). Values are expressed as time in seconds. Comparisons between EIA and EFA data were performed by the Wilcoxon Test. Comparisons between Experimental, Expert, and Intermediate groups data were performed by the Mann-Whitney U Test

collagen, immature collagen, necrosis, congestion, hyperemia, edema, hemorrhage, fibrin, macrophages, multinucleated macrophages, neutrophils, eosinophils, lymphocytes, plasma cells, and bone metaplasia (Table 3). Fibrocytes, mature collagen, hypertrophic fibrocytes, immature collagen, and lymphocytes were the predominant findings in most samples, with scores ranging from mild to moderate to severe (median = 3 to 4). Less predominant findings with a mild grading (median = 2) included congestion, necrosis, macrophages, and angiogenesis. Less frequent findings were hyperemia, neutrophils, multinucleated macrophages, edema, hemorrhage, plasma cells, bone metaplasia, eosinophils, and fibrin. The fragments' microscopic scores shown in Table 3 correspond to three pieces of the gastropexy taken by cross-sectioning the fragments shown in Fig. 10. Accordingly, the most frequent histopathological diagnosis was a mature scar, chronic active inflammation, granulation tissue, foreign body granuloma, and chronic active inflammation foci (Fig. 10).

Macroscopic evidence of bone formation at the gastropexy site was found in specimens of three females (Table 4) as evidenced macroscopically before cutting gastropexy site samples to send to histopathology (See asterisk in Fig. 5, Female 4). Cartilaginous (Fig. 10-D) and bone (Fig. 10E-F) metaplasia were the corresponding microscopic diagnoses. The microscopic evaluation of gastropexy site samples evidenced immature collagen (Fig. 10-A) and mature collagen (Fig. 10B-C) with no evidence of fibrin. Representative microscopic findings in the gastropexy site are depicted in Fig. 10. These findings include immature collagen with active fibroblasts and small vessels (Fig. 10-A9). B. Mature collagen fibers (black arrows) (H&E, 40x). C. Fibrocytes (red arrows) (H&E, 40x). D. Cartilaginous metaplasia with chondrocytes (red arrow) and cartilaginous matrix (asterisks) (H&E, 40x). E. Bone metaplasia (b) surrounded by fibrous bone (fb) (H&E, 10x). F. Bone metaplasia with osteoblasts (red arrow) and bone matrix (asterisks) (H&E, 40x). G. Stomach showing a tertiary lymphoid tissue (Ln) with mononuclear infiltrate comprising macrophages, lymphocytes, and plasma cells. Gastric mucosa (back arrows) and seromuscular (sm) are limited by fat tissue (f) and collagenous tissue (asterisk) (H&E, G.

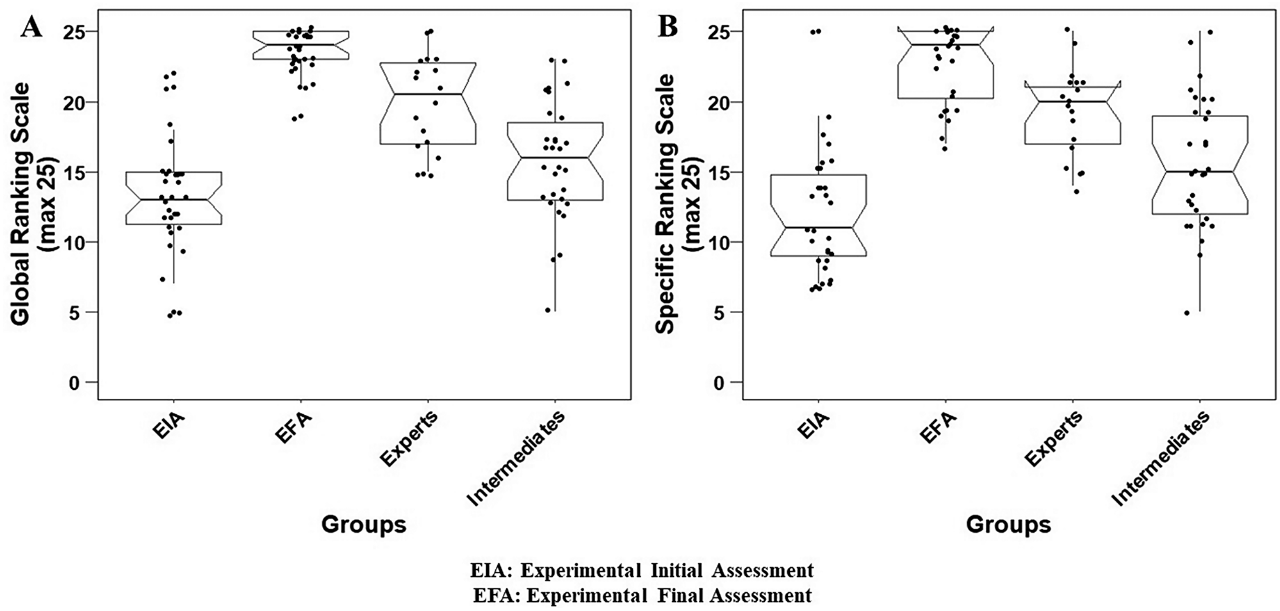

Fig. 7 Notched box and whisker plot of **A**. Global scale and **B**. specific scale obtained by the experimental group before and after the advanced laparoscopic training, compared with the expert and intermediate groups. (Figure interpretation: The boundaries of the boxes indicate the central 50% range of the data, with a center line marking the median value. Lines extend from each box to capture the range of the remaining data, with points located beyond the edges of the lines to indicate outliers. Besides, the notches show the most likely expected values for the median. When making a comparison between groups, we can tell if the difference between the medians is statistically significant based on whether their ranges overlap. If any of the notch areas overlap, it is interpreted as no statistically significant difference; if they do not overlap, the difference is interpreted as statistically significant). EIA, Experimental group initial assessment. EFA, Experimental group final assessment. Experts: Performance veterinarians expert performing MIS. Intermediates: Performance veterinarians with intermediate expertise performing MIS. Values are expressed as Global (**A**) and Specific (**B**) Ranking Scale Units from 1 to 25. Comparisons between EIA and EFA data were performed by the Wilcoxon Test. Comparisons between Experimental, Expert, and Intermediate groups data were performed by the Mann-Whitney U Test

Discussion

The research question proposing that the composed CVTLS simulator and the structured curriculum could provide an effective training for significant transfer of surgical skills to perform TLG in vivo was supported by our results. This study evaluated an advanced laparoscopic training program for TLG by objective assessment (GOALS and SRS) and metrics with a motion tracking sensor using the CVLTS simulator for the first time. The proposed micro curriculum detected differences in surgical performance between groups with different degrees of surgical skill. Besides, it allowed transferring the laparoscopic surgical skill developed on the simulator to the actual surgical environment of TLG in live pigs. Our findings suggest that the training binomial constitutes a valuable didactic tool for acquiring the surgical skills necessary to perform TLG in an actual surgical environment.

In this work, two training evaluation protocols for acquiring laparoscopic skills, GOALS and SRS, were combined with a hands movement assessment system (HMAS) to quantitatively measure the movements performed and the time required to complete the procedures. Accordingly, the experimental group participants significantly improved their surgical performance between the IA and FA measured by GOALS and SRS metrics, as well as by the movement tracking system, resulting in a significant improvement in trainees' movements, resulting in scores higher than the experts. This results where the consequence of learning the curriculum for TLG training, and adapting to the use of instruments. However, the experts did not have the experience with suturing exercises the trainees gained during their training using the simulator. In a paper where subgroups of American College of Veterinary Surgeons (ACVS) certified surgeons currently performing MIS were evaluated for basic laparoscopic exercises, it was found that the scores for extracorporeal and intracorporeal suturing were 0 (0 to 22) and 58 (32 to 77) (on a 0 to 100 scale per task) [9]. In our study, both the expert and intermediate groups only had one opportunity to perform the evaluation, a fact that may had influenced their surgical performance compared to the trainees. All subjects in the experimental group made a loose suture in the initial evaluation due to a technical error, such as loosening the suture knots due to inexperience in managing the monofilament suture. It happened because they had previously trained with silk suture on a Penrose that does not exert any tension between the edges. Only three participants in the intermediate group presented technical errors, which

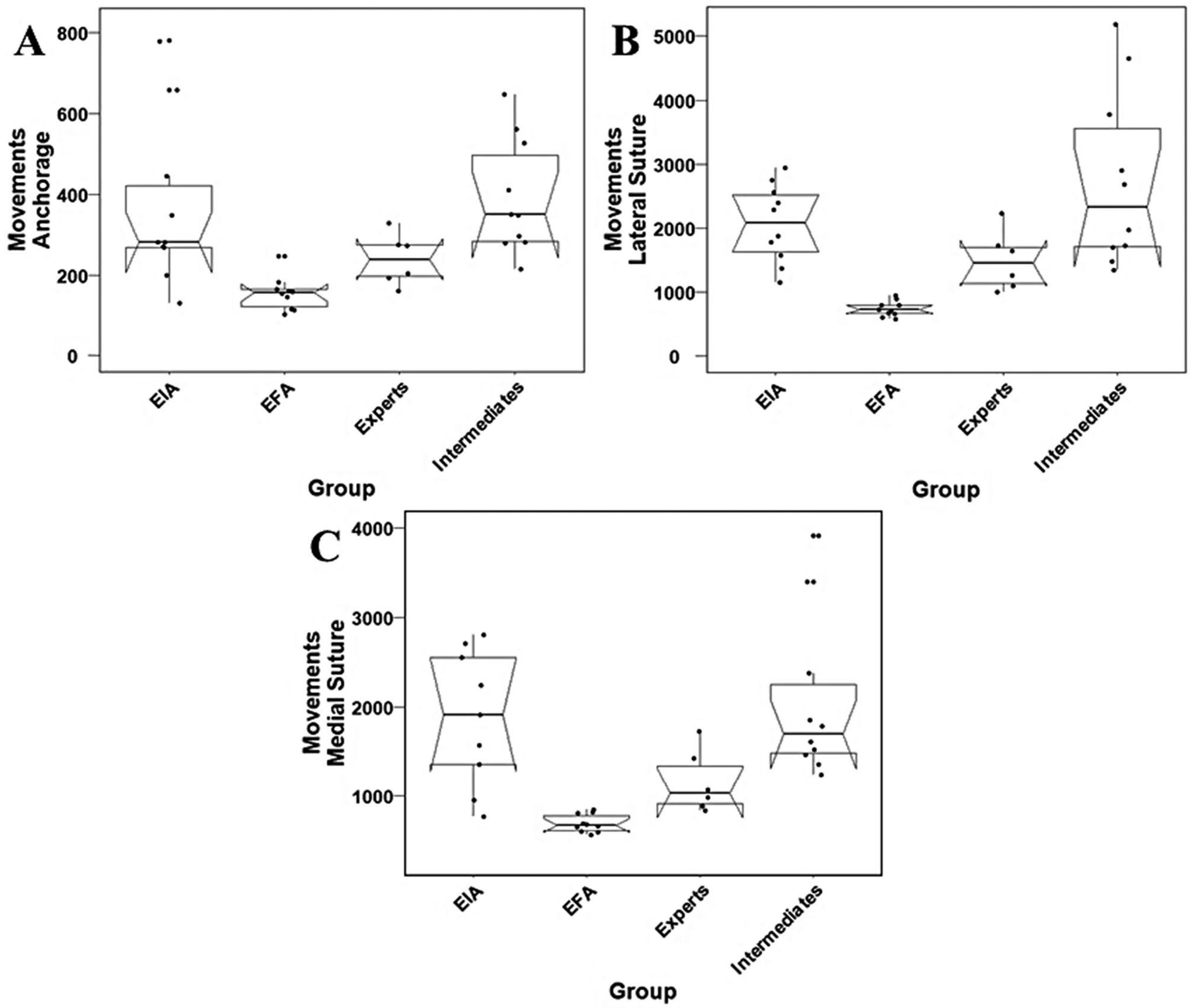

Fig. 8 Notched box and whisker plot of for the number of movements in the anchoring and suturing exercises taken with the HMAS. (Figure interpretation: The boundaries of the boxes indicate the central 50% range of the data, with a center line marking the median value. Lines extend from each box to capture the range of the remaining data, with points located beyond the edges of the lines to indicate outliers. Besides, the notches show the most likely expected values for the median. When making a comparison between groups, we can tell if the difference between the medians is statistically significant based on whether their ranges overlap. If any of the notch areas overlap, it is interpreted as no statistically significant difference; if they do not overlap, the difference is interpreted as statistically significant). Comparisons between EIA and EFA data were performed by the Wilcoxon Test. Comparisons between Experimental, Expert, and Intermediate groups data were performed by the Mann-Whitney U Test. Values are expressed as number of movements

included stomach perforation at the time of cutting and unknotting the suture lines.

The intermediate group of veterinary surgeons' inclusion in the present study aimed to eliminate bias associated with experience in laparoscopic surgery acquired as a primary surgeon in MIS procedures. Despite the difference in the self-reported exposure of this group, the evaluation of surgical performance with GOALS and HMAS did not significantly vary in the experimental group at the initial evaluation ($P > 0.05$). This finding suggests that years of experience do not necessarily transfer into surgical skills, and therefore, it means that to perform MIS it is necessary to perform specific training of intracorporeal suturing.

In a study in which 12-session were performed using a canine abdominal model to training laparoscopic skills' acquisition, the authors found that individuals who trained variable exercises curricula had better performance scores. This was evidenced by basic skills such as surgical performance, unlike exercises based on MISTELS, where improvement is reflected in basic skills [6]. In another study where ten training sessions were evaluated, it was shown that basic skills-based and procedure-based curricula led to veterinary students' laparoscopic surgical skills improvements with no better performance

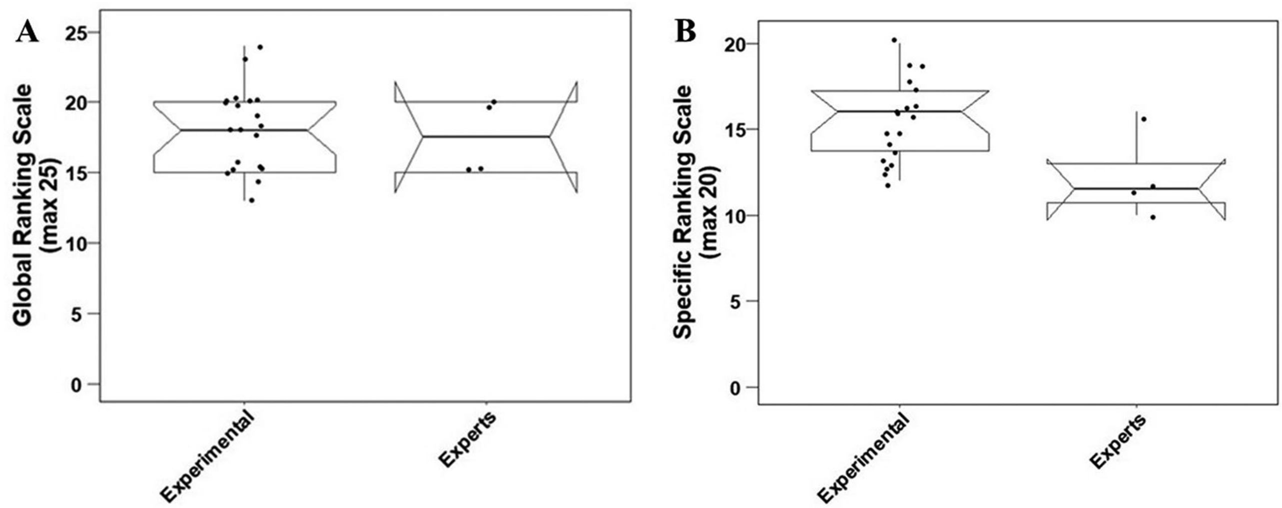

Fig. 9 Notched box and whisker plot of GOALS and SRS scales on the in vivo swine model. (Figure interpretation: The boundaries of the boxes indicate the central 50% range of the data, with a center line marking the median value. Lines extend from each box to capture the range of the remaining data, with points located beyond the edges of the lines to indicate outliers. Besides, the notches show the most likely expected values for the median. When making a comparison between groups, we can tell if the difference between the medians is statistically significant based on whether their ranges overlap. If any of the notch areas overlap, it is interpreted as no statistically significant difference; if they do not overlap, the difference is interpreted as statistically significant). Values are expressed as Global (A) and Specific (B) Ranking Scale Units from 1 to 25. Comparisons between Experimental and Expert groups data were performed by the Mann-Whitney U Test

Table 2 Objective measurements evaluation assessed with the HMAS of surgical performance of apprentices in the experimental group. Comparisons between final evaluation in the CVLT composed training model and total laparoscopic gastropexy in vivo in porcine model

Surgical protocol/ skills variables		The experimental group's final evaluation performed at the CVLT simulator	Experimental group's final evaluation performed at the in vivo porcine model	*p*-value*
Anchorage	Operating time	145,8 (140–151)	256 (160,3-315,3)	**0.02**
	Total movements	153,9 (121,5-163,8)	247, 7 (131,5-271,5)	0.551
	Smoothness of movements	0,287 (0,273-0,298)	0,292 (0,275-0,305)	0.698
	Total angular displacement	2908,7 (2226,4-3303,6)	4613,5 (2279,7-4173,4)	0.481
Cut	Operating time	183,6 (141–252,8)	324,3 (169–407)	0.212
	Total movements	201,4 (131,5-294,5)	252,2 (227,8-262,8)	0.625
	Smoothness of movements	0,26 (0,24 – 0,27)	0,245 (0,24 – 0,25)	0.272
	Total angular displacement	5086,3 (2826,3-7311,5)	6752,6 (5882,8-7207,9)	0.416
Lateral Suture (Final) vs. barbed suture (pig)	Operating time	650,8 (610,8-735,8)	1539 (1171,3-1768,3)	**0.001**
	Total movements	742,5 (668,3-799,5)	1560, 7 (1183,8-1865,8)	**0.001**
	Smoothness of movements	0,313 (0,288-0,328)	0,307 (0,303-0,325)	0.741
	Total angular displacement	25049,3 (21966,7-28839,8)	49,371 (36413,7-62446)	**0.001**
Middle Suturel (Final) vs. barbed suture (pig)	Operating time	612,7 (541,3-671)	1539 (1171,3-1768,3)	**0.001**
	Total movements	692,9 (617,3-779,3)	1560, 7 (1183,8-1865,8)	**0.001**
	Smoothness in movements	0,316 (0,288-0,33)	0,307 (0,303-0,325)	0.467
	Total angular displacement	24404,5 (21982,2-26615,6)	49,371 (36413,7-62447)	**0.001**

Operating Time (Seconds), Total Movements (#), Total Smoothness in movements (#), Total Angular Displacement (Degrees). Comparisons were performed using the Mann-Whitney U test. Operating time (Seconds), Total Movements (#), Total Smoothness in movements (#), and Total angular displacement (Degrees). (Statistically significant differences were established with a P value < 0.05)

in a simulated surgical procedure [17]. Then, we devised a simulator adjusted to the ergonomics of the canine abdomen and an advanced training plan to consolidate the surgical skills of basic sutures applied to a specific surgical technique. We designed a complete pre-training session to acquire basic laparoscopic skills before undertaking this advanced training so that the apprentices would be much more motivated when experiencing the clinical usefulness of learning intracorporeal suturing.

In the 2000s, extracorporeal and intracorporeal suturing was considered as an infrequently used skill in clinical

Table 3 Median microscopic findings in gastropexy site tissue samples recovered postmortem three months after in vivo TLG

	F1			F2			F3			F4			F5			M1			M2			M3			M4			M5	M6		M7		
Fragments	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**1**	**2**	**1**	**2**	**Median**
Fibrocytes	3	3	3	3	4	2	2	4	4	4	4	5	4	2	4	4	4	4	5	3	3	3	3	3	3	4	4	4	5	4	5	4	4
Mature collagen	4	4	4	4	4	1	1	5	5	4	4	4	4	3	4	4	4	4	5	4	3	3	3	3	3	4	4	4	4	5	5	5	4
Hypertrophic Fibrocytes	3	3	5	5	2	5	5	3	3	4	4	1	4	5	2	3	4	3	1	3	4	4	3	3	3	3	3	2	2	2	3	2	3
Immature collagen	3	3	3	3	1	5	5	2	2	4	4	1	2	4	1	3	4	3	1	3	4	4	3	3	3	3	3	2	2	2	3	2	3
Lymphocytes	3	3	3	4	1	3	3	3	3	3	3	4	2	1	1	3	3	2	3	2	3	3	1	1	1	3	3	2	2	4	4	3	3
Congestion	2	1	1	1	1	2	2	1	2	1	1	1	1	2	1	1	2	2	2	2	2	3	2	2	2	2	2	1	2	2	2	2	2
Necrosis	1	3	4	3	1	2	2	3	2	3	3	3	1	1	1	1	4	1	3	1	3	3	1	1	1	3	3	1	1	1	2	2	2
Macrophages	3	3	3	3	1	2	2	3	1	1	2	3	1	1	1	1	3	1	3	1	1	3	1	1	1	3	3	1	1	3	3	3	2
Angiogenesis	1	1	1	1	1	1	1	1	1	1	1	1	2	3	1	2	3	2	2	3	3	4	3	3	2	2	2	1	2	1	2	3	2
Hyperemia	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	4	1	1	1	1	1	1	1	1	1	1	1
Neutrophils	1	1	2	3	1	2	2	2	1	3	2	1	1	1	1	1	3	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1
Multinucleated macrophages	1	3	3	3	1	1	1	1	1	1	2	3	1	1	1	1	3	1	2	1	1	2	1	1	1	3	2	1	1	2	1	1	1
Edema	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1
Hemorrhage	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	2	3	1	1	1	1	1	1
Plasma cells	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	2	2	1	1	2	2	2	1
Bone metaplasia	1	1	5	1	1	1	1	3	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Eosinophils	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1	2	1	2	1
Fibrin	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1

Arbitrary assignemts. 1: Absence; 2: Mild; 3: Mild to moderate; 4: Moderate; 5: Moderate to severe. Because of the nature of data, No estadistical comparisons were performed

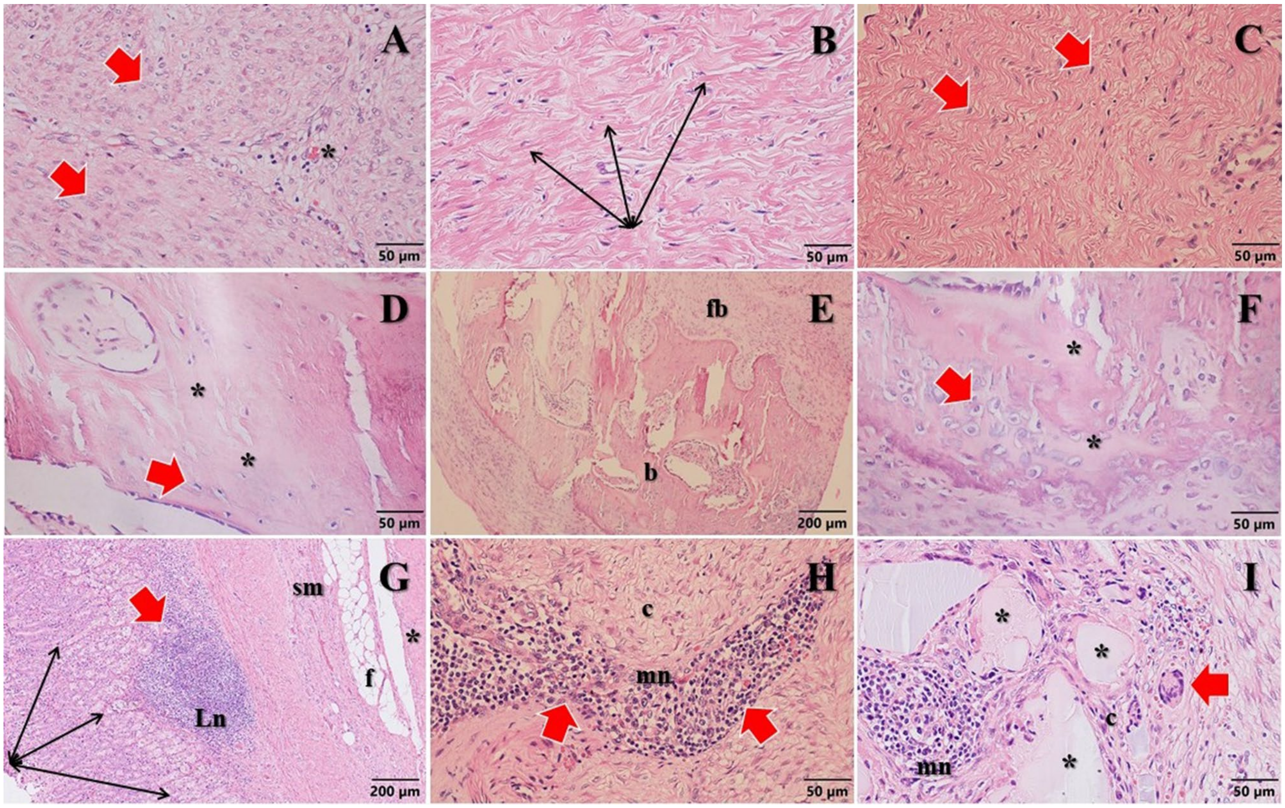

Fig. 10 Microscopic findings in the gastropexy site of finished pigs three months after TLG. **A**. Immature collagen with active fibroblasts (red arrows) and small vessel (asterisk) (H&E, 40x). **B**. Mature collagen fibers (black arrows) (H&E, 40x). **C**. Fibrocytes (red arrows) (H&E, 40x). **D**. Cartilaginous metaplasia with chondrocytes (red arrow) and cartilaginous matrix (asterisks) (H&E, 40x). **E**. Bone metaplasia (b) surrounded by fibrous bone (fb) (H&E, 10x). (F) Bone metaplasia with osteoblasts (red arrow) and bone matrix (asterisks) (H&E, 40x). (G) Stomach showing a tertiary lymphoid tissue (Ln) with a mononuclear infiltrate comprising macrophages, lymphocytes, and plasma cells. Gastric mucosa (back arrows) and seromuscular (sm) are limited by fat tissue (f) and collagenous tissue (asterisk) (H&E, G = 10x). (H) Active chronic inflammation (red arrow) with predominant mononuclear (m) infiltrate, including macrophages, lymphocytes, and plasm cells (H&E, G = 10x; H = 40x). (I) Moderate multifocal chronic active inflammation (m) with multifocal foreign body granulomas (asterisks) and multinucleated macrophages (red arrow) (H&E, 40x)

veterinary surgery [10]. However, a recent study where the ability to master a laparoscopic intracorporeal suture task was evaluated in 10 veterinary medicine students, found that the average number of repetitions necessary to master the skill was 18 ± 7 with an average training time of 67-minute using the simulator and the FLS suture task [21]. Even so, many surgeons prefer the laparoscopy-assisted gastropexy technique because TLG with intracorporeal suture requires a high level of intracorporeal suture experience to minimize operative time and surgical risk [25]. However, to bring the stomach closer to the abdominal wall TLG difficulties include performing the intracorporeal suture and executing the suture knots. Because the barbed suture [22] aimed to solve this inconvenient, in the present study it was decided to incorporate the use of barbed suture to performing TLG on the live pig model. In addition to the economic limitations in training each participant with multiple barbed sutures, arduous training using monofilament suture material and making knots at the beginning and end of each loop would allow students to accept the technique in their learning process. This training would enable them to meet the international TLG standard for GVD prevention.

During suture exercises on the simulator, a laparoscopic needle holder and a counter needle holder were used, whereas, in the live porcine model, using the barbed suture allowed working only with a needle holder. Using the simulator, the monofilament suture, although requiring initial and final knots, requires constant tension to prevent the loops from becoming loose when closing the last stitch of each suture line. In live TLG, using the counter needle holder was avoided because it was not necessary to maintain tension throughout the surgery incision with the barbed suture. Also, triple tying in the initial knot has been reported to reduce the possibility of slippage due to stress and partial evacuation of the pneumoperitoneum during knot tying [23].

Performing predictive validity according to the old validity scale is challenging for competency-based simulation programs because they must demonstrate that what is learned in a surgical training setting is reflected in

Table 4 Description of microscopic findings of gross fragments taken from the gastropexy site after three months post-surgery in growing pigs subjected to TLG in vivo

Sample	Sex	Fragment 1 Stomach serosa	Fragment 2 inner gastropexy	Fragment 3 Costal side
Female 1	F	Mature scar with foci of chronic mononuclear inflammation.	Mature scar. Foreign body granuloma.	Mature scar. Foreign body granuloma. Cartilage metaplasia. Bone metaplasia.
Female 2	F	Mature scar. Foreign body granuloma. Foci of chronic active necrosis.	Mature scar.	Mature scar. Foci of chronic active necrosis.
Female 3	F	Mature scar. Foci of chronic active inflammation.	Mature scar. Foci of chronic active inflammation. Focal bone metaplasia.	Mature scar. Foci of chronic inflammation.
Female 4	F	Mature scar. Focal chronic active inflammation. Bone metaplasia.	Mature scar. Mild multifocal chronic active inflammation. Focal foreign body granuloma.	Mature scar. Moderate multifocal chronic active inflammation. Multifocal foreign body granulomas.
Female 5	F	Mature scar. Granulation tissue. Discrete focal chronic inflammation.	Mature scar. Granulation tissue.	Mature scar.
Male 1	M	Mature scar. Granulation tissue. Mild chronic multifocal inflammation.	Mature scar. Granulation tissue. Multifocal chronic inflammation. Multifocal foreign body granulomas.	Mature scar. Granulation tissue. Focal mild chronic inflammation.
Male 2	M	Mature scar. Granulation tissue. Multifocal foreign body granulomas.	Mature scar. Granulation tissue.	Mature scar. Granulation tissue. Mild multifocal chronic inflammation.
Male 3	M	Mature scar. Granulation tissue. Focal foreign body granuloma.	Mature scar. Granulation tissue.	Mature scar. Granulation tissue.
Male 4	M	Mature scar. Granulation tissue.	Mature scar. Granulation tissue. Multifocal chronic inflammation. Foreign body granuloma.	Mature scar. Granulation tissue. Multifocal chronic inflammation. Foreign body granuloma.
Male 5	M	Mature scar. Mild multifocal chronic inflammation.		
Male 6	M	Mature scar. Granulation tissue. Mild multifocal chronic inflammation.	Mature scar. Granulation tissue. Moderate multifocal chronic inflammation. Focal foreign body granuloma (suture).	
Male 7	M	Mature scar. Granulation tissue. Moderate multifocal chronic inflammation. Multifocal foreign body granulomas (suture).	Mature scar. Granulation tissue. Moderate multifocal chronic inflammation. Focal foreign body granuloma (suture).	

No statistical analysis was performed

an operating room. Our work found that participants in the experimental group achieved significantly better SRS ($P<0.05$), unlike the group of experts. On the other hand, there was no statistically significant difference in GOALS scales during operating room performance between the experimental and the expert groups. Unfortunately, in our work, the comparative metrics of the expert group were not obtained.

The average TLG execution time on the live swine model from the time the instruments were visible on the monitor before anchoring to the barbed suture cutting was around 35 min (256 s (range 160.3–315.3 s) for anchoring, 324.3 s (range 169–407 s) for cutting, and the 1539 s (range 1171.3–1768.3 s) for suturing exercise. In a study comparing the gastropexy time measured from the end of portal placement to the end of the gastropexy in dogs TLG comparing polyglactin 910 u.s.p. 2 – 0 and a laparoscopic-assisted gastropexy (LAG), it was found that the median time for LAG was 28 min (range, 20–40) and 48 min (range, 39–61) for hand-sewn TLG [25].

In a study comparing barbed sutures suturing with a monofilament material in canine laparoscopic gastropexy, authors found that monofilament material significantly improved gastropexy suture time compared to barbed sutures [22]. The time of these studies is different from that of the present study because the TLG techniques were performed with double suture lines. In a work where the surgical time of TLG was evaluated using barbed suture and LAG combined with ovariectomy in dogs, the average surgical time (measured from the first incision to the closure of the last incision) was significantly longer in the TLG group (48 ± 2 min) compared to LAG (39 ± 2 min). In this study, a gastropexy of only 3 cm was performed, the seromuscular layer of the stomach was not incised, and the gastropexy was performed with a suture line as performed in the present study. Accordingly, we suggest that the times obtained by the experimental group are not out of phase, considering that it is a single suture comprising seven loops.

Stabilization of time to perform exercises (exercise execution times) could be interpreted as a signal to decrease the number of sessions (repetitions of that exercise). However, with overtraining, there is an additional benefit beyond stabilizing exercises' execution times. It improves procedural task performance and retention of the learned skill and improves skill transfer compared to less rigorous training [13, 35]. For assessing the surgical protocol time, number and smoothness of movements, and angular displacement for cutting exercise, it was impossible to establish significant differences between the initial and final evaluation and between expert and intermediate groups ($P < 0.05$). The extent of the exercise can explain this finding because a cutting line of 4 to 5 cm started on the seromuscular wall of the pig stomach, and left-hand movement were almost null. Similar results have been reported in other studies comparing the execution times of four tasks between a pre-trained experimental group and a control group, finding significant reductions for the coordination, transfer, and stitching tasks but not for the cutting task [40].

Besides, in our study, the variable "smoothness of movements" did not show significant differences in most exercises for all groups. The smoothness of movements was measured as the mean acceleration of the instrument at each hand movement. In a study where the performance time, number of activities, movement length, and acceleration, was evaluated with OSATS-type competency measures on simulators and actual patients requiring cholecystectomy, it was determined that acceleration showed no significant correlation with any of the conventional markers of a surgical competency [41]. For this reason, it is considered to be not an appropriate discriminatory metric.

Evaluating the simulator transfers and the proposed micro curriculum on the live porcine model with the GOALS and SRS type scale allows accurate evaluation of tissue handling. It is because bleeding and bruising caused by forceps from grasping indicate a participant's poor surgical performance management. The surgical performance criterion achieved at the final assessment by the experimental group after the advanced structured training of 94% for the GOALS and 90.8% for the SRS scale, corroborates the improvement in the execution of the surgical technique. Likewise, the scores were higher than the experts, who reached 79.6% and 76.8% for GRS and SRS, respectively. This reflects the result of the experimental group deliberate practice on the simulator, whereas the experts and intermediate group participants only had one opportunity to perform the exercises. In a study evaluating surgical skills transfer from the training model to the surgical room to perform ovariectomy in bitches, performance criteria of at least 70% (112 out of 160 points) were established to allow individuals in the experimental group to perform surgery on a bitch under operating room conditions [20]. However, later, they recommended scores of 80%. This performance percentage aligns more with previous surgical skill transfer research in human medicine [38].

Clinical signs and complications associated with laparoscopic-assisted and fully laparoscopic techniques are few. During the follow-up between 3 and 12 months after preventive laparoscopic-assisted gastropexy in dogs (PLAG), it was determined that the most frequent clinical finding immediately after surgery was a skin fold at the site of gastropexy ($n = 8/17$; 47%) and up to 12 after surgery ($n = 1/17$; 6%). The complication was seroma formation at the gastropexy site (6%) [42]. In pure laparoscopic gastropexy, minor complications have been described in the immediate postoperative period, such as a decreased appetite for 48 h, depression, inflammation around the incision, and vomiting episodes due to poor management of postoperative feeding and regurgitation [20,23]. In our work, the pigs were followed up for 90 days, during which no clinical manifestation was recorded to denote a complication, especially in these patients under feeding conditions (fattening pigs).

The average period of 135 days to develop the training could have been shorter if participants were affected for the SARS-CovID-19 pandemic mobility restrictions. Likewise, some participants had to isolate themselves occasionally, so the training may be shorter when exclusive dedication exists. Although studies report 110 days with an advanced training plan of 14 sessions, the training plan should have been more straightforward than it was [38]. It is noteworthy that no training maintenance was performed by the experimental group after finishing the training period and before performing the TLG in vivo. In a review on human gynecological minimally invasive surgery training, authors suggest that proficiency could deteriorate over time when it is solely learned and executed on simulation trainers but not on the operating room [42]. However, a specific study evaluating proficiency maintenance after acquiring basic laparoscopic skills using two different simulators found that six months after training both simulator-trained cohorts maintain skill levels not significantly different than the proficiency after the initial training period [43] as corroborated in the study by Scerbo et al. (2017) [44]. Even though the objective of the present study were focused on proficiency acquisition in advanced laparoscopic skills, the results of the experimental group performances in the TLG in vivo suggest they maintain the proficiency acquired in the TLG simulator. However, further studies must include to assess if proficiency is maintained in veterinary trainees. Participants of the experimental group participants strongly agreed with the methodology of the program and the simulation model, with a mean score of 4.7/5 (data not shown). Still, in the future, it is essential to know when the participants will keep the surgical skills they learned in training.

The postmortem macroscopic findings of the gastropexy site showed that eleven out of twelve pigs had a tight junction with no distance between the subcostal peritoneum and the seromuscular layer of the stomach ($n = 8$). Three developed a pedicle, and one formed a weak union, resulting in stomach detachment of the coastal peritoneum when sampling the gastropexy site. These results indicate that 91.6% of the surgeries showed junction stability after 90 days post-surgery. Eight out of nine pigs operated by the trainees presented stable union (88.8%), except the case of female number 2, while the three points of the experts showed stable union (100%). All microscopic analyses indicated the presence of mature scars and variable degrees of chronic inflammation with foci of chronic active reaction; in three cases, bone metaplasia was found, and in three cases, foreign body reaction. We suggest that these reactions result from the stimulus caused by the bearded suture at the gastropexy site, implying that the exacerbated inflammation improved the histologic consistency of the gastropexy in 91.6% of the cases. The case of weak union could have resulted from a poorly executed operative technique, even though a mature scar was also found in the studied fragment. Therefore, this is the first report of histopathological findings in pigs undergoing TLG.

Similar results have been found in a histological study where laparoscopic gastropexy with a linear stapler and incisional gastropexy were evaluated [45]. Variable amounts of fibrin, hemorrhage, mononuclear cell inflammation, loose fibrovascular tissue, and mature collagenous connective tissue characterized gastropexy adhesions in samples in the 7-day postoperative group. At 30 days, they were characterized by a thick band of well-organized fibrous connective tissue and the absence of fibrin, hemorrhage, or immature fibrovascular tissue. Likewise, for the endoscopy-assisted gastropexy evaluated at six months post-intervention, mature granulation tissue, fibrous connective tissue, and muscular tunic were found [18].

The non-inclusion of qualified participants willing to participate in a 14-session training plan could be a limitation of our study. However, the scarce availability of MIS experts in Colombia, the relocation, and the sanitary situation caused by the COVID-19 pandemic did not allow the inclusion of a more considerable number of experts, especially in the Phase 2 assessment. In addition, it was impossible to perform the comparison through HMAS in the final assessment of the live swine model due to technical problems with the sensor during the evaluations with the experts.

Conclusion

According to the GOALS—SRS scale, HMAS metrics, and postmortem findings at the gastropexy site, the experimental group exhibited a statistically significant improvement in surgical MIS skills after practicing the advanced laparoscopic training program for TLG. Training in the CVLTS-composed simulator resulted in the successful transfer of surgical skills for TLG to the operating room in the in vivo model.

Acknowledgements
The authors thank valuable help from Dr. Miguel A. Sánchez-Hurtado, Dra. Julieta Correa Restrepo and Ana M. Mejia-Bueno, for their unconditional support of scientific research, and the Faculty of Medicine, University of Antioquia, for technical support. Special thanks to each veterinarian participant in the study for their effort and dedication to the work. To the Laboratory of Animal Pathology of the Universidad de Antioquia for the photographs to show the histopathological findings of the gastropexy fragments.

Author contributions
CAOP and JGME designed the study. CAOP performed the experimental work and follow-up during training and supervision of the procedures and, together with JGME, performed data analysis and interpretation. JDL-D participated in the experimental design and data analysis of the quantitative measurement device, analyzing and discussing its data. All authors participated in the drafting and critical analysis of the manuscript and read and approved the definitive version of the manuscript.

Funding
The Colombian Minister for Science and Technology (Minciencias) funded this work through a grant to COP (Call # 727, 2015). University of Antioquia by supporting OVHRI and GIBIC Research groups, through "Estrategia de Sostenibilidad para grupos consolidados y en proceso de consolidación 2023". These funding bodies played not a role in the design, analysis and reporting of the study.

Data availability
All data generated in the study are provided in this manuscript. Besides, the supporting files are available for the scientific and veterinary medical community under request.

Declarations

Ethics approval and consent to participate
To support the participation of experts and non-expert veterinarians, the study was conducted following the ethical principles of the World Medical Assembly for research in humans established in its Declaration of Helsinki and approved by the Bioethics Committee on Human Research (protocol code 19-98-872/09102019) of the University of Antioquia, Colombia. For animals used in the in vivo model, the project received the endorsement of the Ethics Committee on Animal Experimentation (protocol code: 131/11022020) of the University of Antioquia, Colombia, for complying with national regulations according to Law 84 of 1989 "By which adopts the National Animal Protection Statute" and regulates the "Use of Live Animals in Experiments and Research" and "scientific, technical and administrative standards for health research are established." Additionally, it complied with international regulations where "Animal Rights" will be respected, as indicated in the Universal Declaration of Animal Rights, adopted by the International League for Animal Rights (1978) and approved by UNESCO and the UN, where it is stated that "all animals have rights". At all times, the research was conducted according to the 3Rs principle ": replace, reduce and refine Russell and Burch (1959). These principles were supported by ethical principles during animal experimentation, according to the Basel Declaration. Finally, this study was part of a larger project designed to evaluate the acquisition of advanced laparoscopic skills and the significant transfer of skill to a surgical protocol. All veterinarians involved in the study signed the informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 30 May 2024 / Accepted: 30 December 2024
Published online: 13 February 2025

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