Significant transfer of surgical skills acquired in an advanced laparoscopic training program for total laparoscopic gastropexy assessed in a live porcine model

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Research Article

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Abstract

Background. Currently, legal limitations avoid repetition and deliberate practice on cadavers and experimental models, which are fundamental for minimally invasive surgery skills acquisition. The CALMA Veterinary Lap-trainer (CVLTS) simulator is an ergonomic canine abdominal model developed to allow training of basic and advanced laparoscopic skills for total laparoscopic gastropexy (TLG) in dogs. This study aimed to evaluate an advanced curriculum using the CVLTS to simulate TLG with intracorporeal suturing and to evaluate the transfer of surgical skills to a live porcine model. Veterinarians trained in basic laparoscopic surgical skills (experimental group, n=10) practiced TLG in 15 training sessions. Performances before and after training were videotaped and compared to veterinary surgeons with intermediate (n=10) or advanced (n=6) laparoscopic skills, including a Hand Movement Assessment System (HMAS). Video records performed before and after training were evaluated by external experts using the Global Operative Assessment of Laparoscopic Skills (GOALS) and TLG-specific scales (SRS) and quantitatively by evaluating HMAS performance. Skill transfer was assessed by performing TLG in fattening pigs under operating room conditions using barbed sutures. Three months after surgery, a postmortem biopsy of the gastropexy site was evaluated by histopathology.

Results

GOALS and SRS scores ($P<0.05$) time, movements, and angular displacement during TLG significantly improved after training within the Experimental group ($P>0.01$) and when compared to expert and intermediate groups ($P<0.05$). The learning curve for intracorporeal suture stabilized since the tenth (out of 15) training session. Besides, trainees achieved significant skill transfer for TLG in the in vivo model, with no significant difference from the expert group. Histopathology findings of the gastropexy site showed mature collagen (100% of cases), cartilage and bone metaplasia, and foreign body reaction (25% of cases), indicating a strong healing process.

Conclusion

The advanced laparoscopic training program for total laparoscopic gastropexy resulted in a statistically significant improvement in surgical skills, as supported by objective assessment score (GOALS - SRS), metrics (HMAS), and postmortem findings at the gastropexy site. Training in the CVLTS simulator resulted in the successful transfer of surgical skills for TLG.

Background

The performance of minimally invasive surgery (MIS) requires specific surgical skills compared to the conventional surgical technique [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 is to allow novices' feedback and evaluation while replicating intervention scenarios of actual patients [3]. Despite the availability of validated simulators for the training of basic and advanced laparoscopic skills in veterinary surgery [4–10], much research is still needed in curriculum development to determine the best methods of laparoscopic skills training [11]. Authors have defined that 2 to 12 training sessions are required to acquire basic laparoscopic skills and to obtain reliable data on training performance [6]. Until now, only one report evaluated the transfer of surgical skills from a simulated environment to an actual surgical environment [13]. Intracorporeal suturing is one of the surgical skills listed as advanced in MIS and one of the most difficult to achieve. Therefore, it is recommended to be practiced on a simulator before being performed on patients to reduce surgical risks, surgical time, and operating room (OR) costs [14]. Acquiring the ability to perform intracorporeal sutures allows MIS surgeons to be more versatile when performing procedures with a purely laparoscopic rather than assisted approach [15]. Although there are multiple techniques for performing prophylactic gastropexy [16, 19], laparoscopic techniques continue to gain acceptance among owners of dogs whose breeds are at higher risk for gastric dilatation-volvulus (GDV). However, this procedure requires special MIS equipment and extensive surgical experience [16, 20]. Currently, total laparoscopic intracorporeal suture gastropexy (TLG) has advantages over the laparoscopy-assisted technique, including lower impact on postoperative recovery, especially in 30kg dogs [16], and reduced postoperative inflammation and infection near the gastropexy site [21, 22]. With the working hypothesis that the advanced laparoscopic training program for laparoscopic gastropexy in the CVLT simulator [23] using ex vivo pig stomach could confer significant transfer of surgical skills when operating in the actual MIS surgical environment, the objective of this study was to evaluate the significant transfer of surgical skills obtained by veterinary surgeons with no experience in veterinary laparoscopy surgery after completing an advanced laparoscopic training program to perform TLG.

Results

Phase 1: Advanced laparoscope training program in TLG

Initial Assessment (IA). Ten volunteer veterinarian surgeons comprised the experimental group of five women and five men, all right-handed, mean age of 30.5 ± 4.3 years, with no laparoscopy surgery experience, and who had previously passed a 10-hour laparoscopic basic skills course on CVLTS. The expert group had a mean age of 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. In the VAS score for experience in MIS, video games, and simulation, means of 88.5mm ± 19.4, 51.3mm ± 31.7, and 77.5mm ± 24.2, respectively, were obtained. The intermediate group had a mean age of 41.2 ± 8.3 years, was made up of nine men and one woman with 6.3 ± 7.7 years of experience in MIS, and all were right-handed. The VAS score for the experience in MIS, video games, and simulation, means of 55.6mm ± 28.0, 34.0mm ± 30.0, and 46.2mm ± 8.6, respectively, were obtained. The final assessment (FA) data were compared with the data from the expert and intermediate groups. Both groups performed the same procedure under identical conditions on the CVLTS. There was a statistical difference between the expert and intermediate group ($P < 0.001$) for MIS experience and age and with the experimental group ($P = < 0.001$). The experience with the simulators had no difference between the experimental and expert groups ($P > 0.05$), but it did with the intermediate group ($P < 0.001$). A significant difference was also found between the experience declared in years ($P < 0.01$) and the VAS ($P < 0.001$) between the expert and intermediate groups. There were no differences in video game experience between the groups.

Before starting the simulated advanced laparoscopic training program, all experimental group members received a master class on TLG with double intracorporeal suture lines on the CVLTS; subsequently, their performance of this technique was evaluated on the same simulator to obtain baseline surgical performance scores. The VAS score for experiences in MIS, videogames, and simulation, ranked between 0mm and 100mm, Mean 0mm ± 0, 57.7mm ± 26.3, and 50mm ± 0, respectively, were obtained. The results of the metric scores (time, number of movements, smoothness in the movements, and angular displacement) measured with the Movement Sensing Device and the global and specific evaluation are presented in Table 1.

Training sessions performance. It required 135 days (4.5 months) to complete the fifteen training sessions of the experimental group. The maximum time per session was 120min. 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 (Fig. 1). 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 the need for additional instructions.

Final Assessment (FA). At the end of the fifteen training sessions, the experimental group participants were again evaluated using the same parameters for the initial assessment (IA). The comparison between the results obtained from the IA and FA of the experimental group and the performance of the intermediates and experts are shown in Table 1 and Fig. 2 (A and B). The experimental group members significantly improved their surgical performance score on the GOALS scales with a mean of 13.1 (range 8.3–20) versus 23.5 (range 21.7–25) ($P < 0.05$); and SRS with a mean of 12 (range 8.3–19.3) versus 22.7 (range 20.3–24.3) ($P < 0.05$). The surgical performance of the experimental group was above 80%. The concordance in the scoring of the three double-blind assessments for the objective assessments was good (0.71 to 0.9) for both the GOALS scale (0.818, $P < 0.0001$) and the SRS scale (0.71, $P < 0.0001$).

Motion sensor measurements. Except for the cutting exercise, the HMAS records in operative time, movements, and angular displacement for both hands decreased significantly in all exercises between the IA and FA of the experimental group ($P < 0.01$), with significantly better results than the experts and the intermediates group. (Table 1; Fig. 3. A, B, and C). Statistically significant differences between the AI of the experimental group and the expert group were found in the objective evaluation with the GOALS ($P < 0.01$) and SRS ($P < 0.01$) scales. Likewise, differences were only found with the HMAS in time for the cutting ($P < 0.01$) and lateral suture ($P < 0.05$) exercises. The metrics of smoothness in movements did not show sensitivity to distinguish between groups and tasks.

Phase 2: TLG using barbed suture on a porcine model.

In an instruction (training) session, the participants in the experimental group were taught to perform an LGT using the barbed suture. The members found the surgical technique easier with this type of device on the simulator.

Evaluation of the TLG on the porcine model in the operating room. The performance of the experimental group members on the TLG in a live swine model (Fig. 4) was compared with the performance of the exact procedure of two experts through the GOALS and SRS scales. All participants completed the TLG without requiring manual intervention by the principal investigator. In some cases, minor verbal cues that did not involve the development of the trained surgical technique were given (e.g., on ergonomics, CO_2 pressure, care of instruments in the abdominal cavity, part reassurance on the steps to participants in the experimental group). Ten pigs underwent surgery, of which nine were followed up for 90 days. One pig died during the postoperative period in the recovery room due to cardiorespiratory arrest, which did not interfere with participant data collection. The results obtained for the experimental group were significantly better for SRS 15.7 ± 2.5 of the experimental group versus 12.3 ± 2.6 of the expert group ($P < 0.05$). There was no statistical difference between the experimental group (18.1 ± 3) and the expert group (17.5 ± 2.9) for the GOALS evaluation ($P > 0.05$). The concordance of the ratings of the two evaluators by Intraclass Correlation Coefficient - ICC to observe the reliability or level of agreement in their respective estimates for this Phase was moderate for GOALS (0.803, $P < 0.01$) and suitable for SRS (0.646, $P < 0.01$) (Fig. 5). The results of six participants in the experimental group whose surgical ability was evaluated with the motion sensor are presented in Table 2.

Postmortem macroscopic findings at the gastropexy site. The gross findings at the gastropexy sites included (Figs. 6 and 7): 1. A tight junction between the seromuscular layer of the stomach and the subcostal peritoneum (samples F1, F3, F4, F5, M1, M2, M3, M4, and M6). 2. Union through a short pedicle (< 1 cm) (samples M5 and M7). 3. Union through a long pedicle (> 1 cm) (sample F5). and 4. Weak connection through a pedicle dislodged when applying slight traction to take the sample (sample F2).

Histological findings. For histopathological examination, the absence (1), or mild (2), mild to moderate (3), moderate (4), and moderate to severe (5) presence of the following microscopic elements at 100X magnification were considered: Fibrocytes, Hypertrophic fibrocytes, Angiogenesis, Mature collagen, Immature collagen, Necrosis, Congestion, Hyperemia, Edema, Hemorrhage, Fibrin, Macrophages, Multinucleated macrophages, Neutrophils, Eosinophils, Lymphocytes, Plasma cells and Bone metaplasia (Table 3). The predominant finding common to most samples with scores ranging from mild to moderate to severe (median = 3 to 4) were fibrocytes, mature collagen, hypertrophic fibrocytes, immature collagen, and lymphocytes. Less predominant common 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 (Table 3). The fragments in Table 3 correspond to three segments taken after a cross-section of the gastropexy fragments shown in Fig. 8. Consequently, the most frequent histopathological diagnosis was a mature scar in all fragments, chronic active inflammation, granulation tissue, foreign body granuloma, and foci of chronic active inflammation (Fig. 8).

An unexpected finding was bone metaplasia in the gastropexy specimens of three females (Table 4) that had been detected in the macroscopic examination when cutting samples to send to histopathology (Fig. 7, Female 4), resulting in a microscopic diagnosis of cartilaginous (Fig. 8-D) and bone (Fig. 8E-F) metaplasia. Following the physiological process found at the macroscopic exam, microscopic evaluation evidenced immature collagen (Fig. 8-A) and mature collagen (Fig. 8B-C) with no evidence of fibrin. Other microscopic findings are indicated in Fig. 8.

Discussion

In this study, for the first time, an advanced laparoscopic training program for TLG was evaluated by objective assessment (GOALS and SRS) and metrics with a motion tracking sensor using the CVLTS simulator. The results of the present study indicate that the simulator and the proposed micro curriculum detected differences in surgical performance between groups with different degrees of surgical skill. In addition, 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 to acquire the surgical skill necessary to perform TLG in the actual surgical environment.

In this work, two training evaluation protocols for acquiring laparoscopic skills, GOALS and SRS, were combined and complemented with a device for the quantitative measurement of the movements performed and the time required to complete the procedures. Two metrics 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) [2, 29]. Other metrics include the widely validated Objective Structured Assessment of Technical Skills (OSATS) scale [30, 31], which includes a global rating scale (GRS) and a specific rating scale (SRS), a checklist of specific tasks, or the Operational Component Rating Scale (OCRS) [6]. Based on the OSATS guidelines, it was designed the Global Operative Assessment of Laparoscopic Skills Scale (GOALS) specifically for minimally invasive procedures [32]. OSATS and MISTELS-type metrics strongly correlate with MIS experience level for evaluating basic veterinary laparoscopic surgical performance [6–8]. In the present study, 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 the movements of trainees, whose results showed some performances with scores higher than the experts. We deduce that this results from training, familiarization with the instruments, and evaluation method, although experts did not have the suture experience using the simulator that the trainees gained during training. In a paper where subgroups of American College of Veterinary Surgeons (ACVS) certified surgeons active in 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 scale where 100 was the maximum score per task [6]. In our study, both the expert and intermediate groups only had one opportunity to perform the evaluation, a fact that may influence the outcome of the surgical performance of these participants compared to the trainees. All subjects in the experimental group made a loose suture in the initial evaluation due to a technical error unknotting the sutures due to inexperience in handling 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 included perforation of the stomach at the time of cutting and unknotting the suture lines.

Including the intermediate group of veterinary surgeons in this study was 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 initial evaluation ($P > 0.05$). This finding suggests that years of experience do not translate into surgical skill, and therefore, specific training in intracorporeal suturing is necessary to perform suture-demanding MIS.

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 in deconstructing a complex task into simpler components (exercises) for practice. For this reason, the student must acquire proficiency in individual exercises before advancing to a more complex exercise until task completion [27]. 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]. The effects of 10 practical sessions were evaluated in laparoscopic suturing simulation resulting in novices being able to safely complete oophorectomy in bitches with extra and intracorporeal ligation [33].

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, and as he learns it, a new exercise is added until reaching a sequence of basic knowledge that will allow you to develop the task that you wanted to learn [28, 34]. 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 actual surgical environment, they required minimal indications [34]. They could dedicate fewer attention resources to these automated tasks and focus on tasks dependent on surgical function [31, 35]. 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 assessing surgical performance, deliberate practice in distributed sessions with appropriate feedback, and even over-training as reported in other studies [9, 19].

In a study using a canine abdominal model for 12-session training on laparoscopic skill acquisition, it was found that individuals training varied exercise curricula had better scores. That was evidenced for basic skills such as surgical performance, unlike exercises based on the MISTELS, where the improvement is reflected in basic skills [8]. In another study where ten training sessions were evaluated, it was shown that both basic skills-based and procedure-based curricula led to veterinary students' laparoscopic surgical skills improvements with no better performance in a simulated surgical procedure [12]. These works motivated us to devise a simulator adjusted to the ergonomics of the canine abdomen and an advanced training plan that would allow consolidation of the surgical skill of basic sutures applied to a specific surgical technique. We propose that students complete a pre-training in basic laparoscopic skills before undertaking this advanced training to be much more motivated when palpating the clinical usefulness of learning intracorporeal suturing.

In the 2000s, extracorporeal and intracorporeal suturing was considered an infrequently used skill in clinical veterinary surgery [7]. However, a recent study where the ability to master a laparoscopic intracorporeal suture task was evaluated in 10 veterinary medicine students determined that the average number of repetitions necessary to master the skill was 18 ± 7 with an average time of 67-minute training using the simulator and the FLS suture task [14]. Even so, many surgeons prefer the laparoscopy-assisted gastropexy technique because TLG with intracorporeal suture requires a high level of experience in the intracorporeal suture to minimize operative time and surgical risk [21]. However, the difficulties of TLG not only include performing the intracorporeal suture but also the difficulty of executing the suture knots to bring the stomach closer to the abdominal wall, an item that is solved with the barbed suture [15]. This was why it was decided to change the final technique on the live pig model. In addition to the economic limitations involved 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 better and incorporate the technique in their learning process. This training would allow them to adjust to the international standard of the TLG for the prevention of GVD.

During suture exercises on the simulator, a laparoscopic needle holder and a counter needle holder were used, whereas, in the live porcine model, it was only used the needle holder due to barbed suture use. 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 using the simulator. In live TLG, it was not necessary to use the counter needle holder because it is not necessary to maintain tension throughout the surgery with the barbed suture. Also, triple tying in the initial knot has been reported to reduce the possibility of slippage due to tension and partial evacuation of the pneumoperitoneum during knot tying [16].

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 setting is reflected in 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 between the experimental group and the group of experts for the evaluation with GOALS during the evaluations in the operating room. Unfortunately, in our work, the comparative metrics of the experts were not obtained.

The average execution time of the TLG used on the live swine model counted from the time the instruments were visible on the monitor before anchoring to the cutting of the barbed suture was 256sec (range 160.3-315.3 sec) for anchoring, 324.3sec (range 169–407 sec) for cutting, and the 1539sec (range 1171.3-1768.3 sec) for suturing exercise with barbed suture. In a study comparing the gastropexy time used (measured from the end of portal placement to the end of the gastropexy) in dogs between a TLG with polyglactin 910 #2 – 0 and a laparoscopic-assisted gastropexy (LAG), it was found that the median time for LAG was 28min (range, 20–40) and 48min (range, 39–61) for hand-sewn TLG [16].

In a study comparing suturing with barbed sutures and a monofilament material in canine laparoscopic gastropexy, authors found that using monofilament material significantly improved gastropexy suture time compared to barbed sutures [36]. The time of these studies is different from ours 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 bitches, it was found that 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 3cm was performed, the seromuscular layer of the stomach was not incised, and the gastropexy was performed with a suture line as in our study. Due to the above, we suggest that the times obtained by the experimental group are not out of Phase, considering that it is a single suture line for which a total of seven loops were made.

Stabilization of exercise execution times could be interpreted as a signal to decrease the number of sessions (repetitions of that exercise). However, we believe that with overtraining, there is an additional benefit beyond the stabilization of exercise execution times in that it improves procedural task performance and retention of the learned skill and improves skill transfer compared to less rigorous training [11, 27]. For assessing the time of surgical protocol, the number of movements, abruptness, and angular displacement for cutting exercise, it was not possible to establish significant differences between the initial and final evaluation, as well as between expert and intermediate groups. The extent of the exercise can explain this finding because a cutting line of approximately 4 to 5 cm started on the seromuscular wall of the pig stomach, and left-hand movement was 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 [25].

Additionally, in our study, the abruptness variable did not show significant differences in most exercises for all groups. Roughness was measured as the mean acceleration of the instrument at each hand movement. In a study where the performance markers time, number of movements, movement length, and acceleration, 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 competency [37]. For this reason, it does not seem to be an appropriate discriminatory metric.

The evaluation of the simulator transfers and the proposed micro curriculum on the live porcine model with the GOALS and SRS type scale has the advantage of allowing accurate evaluation of tissue handling because bleeding and bruising caused by forceps bruising from grasping is indicative of poor surgical performance management of a participant. The surgical performance criterion achieved at the final assessment by the experimental group of 94% for the GOALS and 90.8% for the SRS scale after advanced structured training corroborates the improvement in the execution of the surgical technique. Likewise, the scores were higher than the experts, who reached 79.6% for the GRS and 76.8% for the SRS. This reflects the result of deliberate practice on the simulator, as well as the fact that the experts and intermediate group participants only had one opportunity to execute the exercises. In a study evaluating the transfer from the simulated to the surgical environment for 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 [13]. However, later they recommended scores of 80%. This performance percentage aligns more with previous surgical skill transfer research in human medicine [34].

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 canines (PLAG), it was determined that the most frequent clinical finding was a skin fold at the site of gastropexy immediately after surgery (n = 8/17; 47%) and up to 12 after surgery (n = 1/17; 6%). The complication was seroma formation at the gastropexy site (6%) [38]. In pure laparoscopic gastropexy, in the immediate postoperative period, minor complications have been described, such as a decreased appetite for 48 hours, depression, inflammation around the incision, and vomiting episodes due to poor management of postoperative feeding and regurgitation [16, 36]. 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).

The average period of 135 days to develop the training could have been shorter if not for the mobility restrictions due to the health emergency caused by the SARS-Covid 19 pandemic. Likewise, some participants had to isolate themselves occasionally, so the training may be shorter when there is exclusive dedication. Although studies report 110 days with an advanced training plan of 14 sessions, the training plan was not as long as it should have been [34]. 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), but we believe that in the future, it is essential to know the time during which the participants keep surgical skills 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). Pedicle development (n = 3) and weak union (n = 1) resulted in stomach detachment of the costal peritoneum when the stomach was taken to detach the gastropexy fragment for sampling. These results indicate that 91.6% of the surgeries showed stability of the junction after 90 days postoperatively. Eight out of nine pigs operated by the trainees presented stable union (88.8%), except the case of female number 2, while the three cases of the experts showed stable union (100%). All microscopic analyzes 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, suggesting that the exacerbated inflammation improved the histologic consistency of the gastropexy in 91.6% of the cases. The only 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 LGT.

Similar results have been found in a histological study where laparoscopic gastropexy with a linear stapler and initial gastropexy was evaluated [39]. Gastropexy adhesions in samples in the 7-day postoperative group were characterized by variable amounts of fibrin, hemorrhage, mononuclear cell inflammation, loose fibrovascular tissue, and mature collagenous connective tissue. 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 [17].

Some limitations of our study included no inclusion of qualified and willing participants in a 14-session training plan is minimal. The availability of experts in Colombia, the relocation, and the sanitary situation caused by COVID-19 did not allow the accumulation of a more considerable number of experts for both phases, especially for Phase 2. 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

The proposed advanced laparoscopic training program and use of the CVLTS simulator for TLG were effective and confident in improving the surgical skill required to perform TLG in vivo. The skills level of novices achieved after CVLTS training and during in vivo TLG performance was equal to or better than the expert level.

Methods

Type of study. The analytical (experimental) study is a randomized controlled trial type. 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 prior to their participation. 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).

Phase 1: Advanced Laparoscopic Training Program in TLG. The experimental curriculum was evaluated in (i) veterinarians pre-trained in basic laparoscopic surgery skills who voluntarily accepted participation in training total laparoscopic gastropexy with intracorporeal suture (TLG) in the CVLTS simulator [23] (experimental group, n = 10). (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 as leading surgeons for the entire TLG procedure, with a minimum of 3 years of experience and more than 30 MIS procedures [24, 25] (expert group, n = 6). Participants fill out 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 was assessed through a visual analog scale (VAS) from 0mm to 100mm defined as follows: for MIS level of experience, 0mm indicated no experience at all, 50mm: indicated the surgeon had performed a minimum of 10 procedures as the leading surgeon, and 100mm indicated 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: 0mm indicated they had never conducted simulator training, 50mm indicated they had occasionally used simulators, including short representative courses or commercial samples, and 100mm 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, 0mm indicated they had never played any kind of video games, and 50mm indicated they had occasionally played video games in the last three years or played video games regularly (from 0 to 3 hours per week during more than a year) more than five years ago, but not in the last five years, 100mm indicated had played video games daily to weekly during the last three years, or for more than three hours per week for a minimum of eight years.

Initial Assessment (IA). 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 holding 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-blind 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. With this data, we 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 [26]. Technical errors such as mucosal permeability and suture lines untying were also evaluated by direct stomach visualization once the evaluation was completed. Each participant had a maximum of two hours to complete the TLG. The test finished if any participant exceeded this time or gave up following exercises. Participants could adjust the simulator position according to their height, and the monitor was adjusted to their eye level on demand.

After finishing the theoretical session, the advisory was provided to any participant still having doubts about the TLG procedure. Participants were allowed to 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 test 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 did not perform the training sessions.

Training Sessions

After the IA, the experimental group started a 15-session training program built considering critical aspects such as theoretical sessions, deliberate practice, sequence steps, and progressive, cumulative experience [3, 27, 28]. 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 scheduled into four basic exercises (Fig. 9), including:

1. Anchoring exercise (corresponding to training sessions 1 to 3), which comprised suturing the stomach to the abdominal wall, using a non-absorbable polyamide monofilament suture N° 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. 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. 10. 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.

2. Cutting exercise (corresponding to training sessions 4 to 6) consisted of the incision of the serous-muscular layer of the stomach approximately 4 to 5cm 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. 10B). The participant had to repeat the above exercise four times in each session. The duration time was recorded from the introduction of the scissors until the last cut was made on the stomach seromuscular layer.

3. Suturing exercises (corresponding to cranial and caudal borders suturing). Suturing was performed using a non-absorbable polyamide monofilament suture N° 2 – 0, 19 cm long with a 25 mm needle with a ½-circle round tip using a simple continuous pattern. The introduction of the needle into the simulator was performed 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. 10C). Once the previous exercise was completed, the second piece of suture was introduced, the caudal margin was sutured to complete the gastropexy (Fig. 10. 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 performed with a reusable laparoscopic needle holder curved type V-style handle and a contra needle holder.

Final Assessment (FA). After completing the training program, all the experimental group participants were evaluated under the same standards of IA. Data were compared with data from intermediate and expert groups.

Phase 2: TLG using barbed suture on a porcine model.

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, 2 – 0 with GS-22 round needle, 27mm 1/2 Circle, VLOCL2105.), according to the techniques by Mayhew and Brown (2009) [16]. 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, and the bearded suture had to include the four edges of the two incisions (Fig. 4C-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 used in Phase 1 on the simulator, but now on a live patient under operating room conditions. Two MIS experts sent video records evaluation under double-blind mode for surgical performance assessment using GOALS and SRS scales, as previously mentioned. 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.

In Vivo Tlg Protocol

Anesthetic protocol. 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 (10mg/kg; i.v.), Xylazine (1.5mg/kg; i.v.), and atropine (0.05 mg/kg; i.v.). Ketoprofen (2.2mg/kg; i.m) for as analgesia and then at 24-hour intervals for three postoperative days. In addition, 1.5ml 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 hours after that for five days. For induction, it was used a combination of Propofol (2mg/kg; i.v), Fentanyl (2ug/kg; i.v), and Dexamethasone (0.3mg/kg) was used. For anesthesia maintenance, it was used 2% Isoflurane and 1.5 L/min oxygen flow through an anesthetic machine. Additionally, 0.2mg/kg ondansetron was administered by i.v. infusion. During the recovery process, Yohimbine (0.05 mg/kg) diluted in SSF slowly, by i.v. infusion was applied. All patients recovered with 1 L/min oxygen support, and safe extubating was only performed when each pig exhibited palpebral reflex, swallowing, and normal 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. An ectoparasiticide ointment based on trichlorfon, metrifonate, phenol, and pine oil was also applied around the wound.

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. To place the first 11mm portal (Kii Fios, Applied Medical, CA, USA) for lens positioning, a ventral midline incision was made 3cm 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 inserted into the peritoneal cavity. Under direct vision, an 11 mm portal (Kii Fios, Applied Medical, CA, USA) was placed 3 cm caudal to the xiphoid process above the alba line, and a second 5mm portal was placed 2cm infra umbilically and located right paramedian. The principal researcher made the ports and pig positioning. Immediately the experimental and expert group surgeons could manipulate the laparoscopic atraumatic grasping forceps (5mm x 330mm) inside the abdominal cavity if the stomach antrum were not immediately visible until obtaining an adequate view to perform the anchoring suture. 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) N° 2 – 0 of 75 cm length with a 3/8 circle needle of 35mm 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 costal peritoneum was performed (Fig. 4C and D). Subsequently, a partial incision was made in both layers: up to the transverse muscle in the abdominal wall, using a laparoscopic curved Metzenbaum scissor (5mm x 330mm).

Through the 11mm portal, a 2 – 0 barbed suture was introduced with a GS-22 round needle, with a 27mm 1/2 circle needle (V-Loc™ 180® Covidien VLOCL2105) to suture the transversus abdominis muscle and stomach antral incisions linearly. 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 introduced 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 complete turn. Finally, the direction of the barbed suture was reversed to secure it in the tissue. The suture was cut with scissors for material (Fig. 4), and the temporary anchor was removed.

Postoperative follow-up. All pigs have cared for in the recovery area of the veterinary hospital, where they received 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. We were noticed by the farmer 24 hours 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 completed their finishing period. So, the farmer never reported any post-surgical complications.

2.3 Surgical Performance Criteria. The competence criterion to perform the TLG on the live pig model by the experimental group participants was established at a minimum score of 20 points out of a possible 25 (equivalent to 80%) on the GOALS and SRS scales [13].

2.4 Postoperative follow-up and postmortem gastropexy evaluation. All operated animals were fed with 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). No intervention of the research group was performed on pigs from post-operatory recovery until completed their finishing period. So, the farmer never reported any post-surgical complications. Upon notice by the farmer 24 hours 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 procedure. Then we went to the slaughterhouse for postmortem sampling of the gastropexy site.

At the dressing line, the carcasses were checked before eviscerating white viscera, and a photograph of the gastropexy attachment site (Fig. 6). 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 sample was photographed and evaluated for macroscopic description (Fig. 7).

2.5 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 um cuts were made, mounted in glass slides, and processed for H&E staining. The plates were read by a veterinary histopathologist with more than 20 years of experience. This laboratory is certified and conforms to the standards of the United States Army Pathology Laboratory. The reading of the plates was done 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. The variables of the objective assessment of surgical performance (GOALS, SRS, and motion data) between groups were compared with the Mann-Whitney U test. The Wilcoxon test was used to compare pre-and post-training assessments. 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. The association between the demographic variables with the evaluations was determined with the Spearman Correlation Coefficient. Using regression models, the training time was estimated. 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.

Declarations

Ethics approval and consent to participate.

The study was conducted following the principles of the World Medical Assembly established in its Declaration of Helsinki and approved by the Bioethics Committee on Human Research (protocol code: 19-98-872/09102019) and the Ethics Committee on Animal Experimentation (protocol code: 131/11022020) of the University of Antioquia, Colombia. 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 subjects involved in the study signed the informed consent.

Consent for publication

Not applicable.

Availability of data and materials

All data generated in the study are provided in this manuscript. However, it is available for the scientific and medical community under request.

Competing interest

The authors declare that they have no competing interests.

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Authors contribution

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. All authors participated in the drafting and critical analysis of the manuscript and read and approved the final version of the manuscript.

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References

1. Tapia-Araya AE, Martin-Portugués IDG, Sánchez-Margallo FM. Veterinary laparoscopy and minimally invasive surgery. Companion Anim. 2015;20:382–92. 10.2460/ajvr.77.2.186.
2. Fransson BA. Advances in laparoscopic skills training and management. Vet Clin North Am Small Anim Pract. 2016;46:1–12. 10.1016/j.cvsm.2015.08.002.
3. Okuda Y, Bryson EO, DeMaria S Jr, Jacobson L, Quinones J, Shen B, Levine AI. The utility of simulation in medical education: what is the evidence? Mt Sinai J Med. 2009;76:330–43. 10.1002/msj.20127.
4. Fransson B. The future: taking veterinary laparoscopy to the next level. J Feline Med Surg. 2014;16:42–50. 10.1177/1098612X13516571.
5. Usón-Gargallo J, Tapia-Araya AE, Díaz-Güemes Martin-Portugués I, Sánchez-Margallo FM. Development and evaluation of a canine laparoscopic simulator for veterinary clinical training. J Vet Med Educ. 2014;41:218–24. 10.3138/jvme.0913-136R1.
6. Fransson BA, Ragle CA, Bryan ME. A laparoscopic surgical skills assessment tool for veterinarians. J Vet Med Educ. 2010;37:304–13. 10.3138/jvme.37.3.304.
7. Fransson BA, Ragle CA. Assessment of laparoscopic skills before and after simulation training with a canine abdominal model. J Am Vet Med Assoc. 2010;236:1079–84. 10.2460/javma.236.10.1079.
8. Fransson BA, Ragle CA, Bryan ME. Effects of two training curricula on basic laparoscopic skills and surgical performance among veterinarians. J Am Vet Med Assoc. 2012;241:451–60. 10.2460/javma.241.4.451.
9. Chen CY, Elarbi M, Ragle CA, Fransson BA. Development and evaluation of a high-fidelity canine laparoscopic ovariectomy model for surgical simulation training and testing. J Am Vet Med Assoc. 2019;254:113–23. 10.2460/javma.254.1.113.
10. Elarbi MM, Ragle CA, Fransson BA, Farnsworth KD. Face, construct, and concurrent validity of a simulation model for laparoscopic ovariectomy in standing horses. J Am Vet Med Assoc. 2018;253:92–100. 10.2460/javma.253.1.92.
11. Stefanidis D. The Formula for a Successful Laparoscopic Skills Curriculum. Arch Surg. 2009;144:77. 10.1001/archsurg.2008.528.
12. Chen CY, Ragle CA, Lencioni R, Fransson BA. Comparison of 2 training programs for basic laparoscopic skills and simulated surgery performance in veterinary students. Vet Surg. 2017;46:1187–97. 10.1111/vsu.12729.
13. French ED, Griffon DJ, Kass PH, Fahie MA, Gordon-Ross P, Levi O. Evaluation of a laparoscopic abdominal simulator assessment to test readiness for laparoscopic ovariectomy in live dogs. Vet Surg. 2021;50(Suppl 1):O49–O66. 10.1111/vsu.13604.
14. Kilkenny JJ, White K, Singh A. Evaluating veterinary student skill acquisition on a laparoscopic suturing exercise after simulation training. Vet Surg. 2019;48(Suppl 1):O66–73. 10.1111/vsu.12930.
15. Huhn JC. Advances in Equipment and Instrumentation in Laparoscopic Surgery. Vet Clin North Am Small Anim Pract. 2016;46:13–29. 10.1016/j.cvsm.2015.08.005.
16. Mayhew PD, Brown DC. Prospective Evaluation of Two Intracorporeally Sutured Prophylactic Laparoscopic Gastropexy Techniques Compared with Laparoscopic-Assisted Gastropexy in Dogs. Vet Surg. 2009;38:738–46. 10.1111/j.1532-950X.2009.00554.x.
17. Dujowich M, Reimer SB. Evaluation of an endoscopically assisted gastropexy technique in dogs. Am J Vet Res. 2008;69:537–41. 10.2460/ajvr.69.4.537.
18. Rawlings CA, Foutz TL, Mahaffey MB, Howerth EW, Bement S, Canalis C. A rapid and strong laparoscopic-assisted gastropexy in dogs. Am J Vet Res. 2001;62:871–5. 10.2460/ajvr.2001.62.871.
19. Mathon DH, Dossin O, Palierne S, Cremoux M, Rodriguez H, Meynaud-Collard P, Steiner JM, Suchodolski JS, Lefebvre HP, Autefage A. A Laparoscopic-Sutured Gastropexy Technique In Dogs: Mechanical and Functional Evaluation: Laparoscopic-sutured gastropexy in dogs. Vet Surg. 2009;38:967–74. 10.1111/j.1532-950X.2009.00592.x.
20. Allen P, Paul A. Gastropexy for Prevention of Gastric Dilatation-Volvulus in Dogs: History and Techniques. Top Companion Anim Med. 2014;29:77–80. 10.1053/j.tcam.2014.09.001.
21. Leonardi F, Properzi R, Rosa J, Boschi P, Paviolo S, Costa GL, Bendinelli C. Combined laparoscopic ovariectomy and laparoscopic-assisted gastropexy versus combined laparoscopic ovariectomy and total laparoscopic gastropexy: A comparison of surgical time, complications and postoperative pain in dogs. Vet Med Sci. 2020;6:321–9. 10.1002/vms3.249.
22. Loy Son NK, Singh A, Amsellem P, Kilkenny J, Brisson BA, Oblak ML, Ogilvie AT. Long-Term Outcome and Complications Following Prophylactic Laparoscopic-Assisted Gastropexy in Dogs: Prophylactic Laparoscopic-Assisted Gastropexy. Vet Surg. 2016;45(S1):O77–83. 10.1111/vsu.12568.
23. Oviedo-Peñata CA, Giraldo-Mejia GE, Riaño-Benavides CH, Lemos Duque JD, Maldonado-Estrada JG. Development and validation of a composed canine simulator for advanced veterinary laparoscopic training. Front Vet Sci. 2022;7:306. 10.3389/fvets.2022.936144.
24. Fransson BA, Chen CY, Noyes JA, Ragle CA. Instrument motion metrics for laparoscopic skills assessment in virtual reality and augmented reality: motion metrics for laparoscopic skills assessment. Vet Surg. 2016;45:O5–13. 10.1111/vsu.12483.
25. Tapia-Araya AE, Usón-Gargallo J, Enciso S, Pérez-Duarte FJ, Díaz-Güemes Martin-Portugués I, Fresno-Bermejo L, Sánchez-Margallo FM. Assessment of laparoscopic skills in veterinarians using a canine laparoscopic simulator. J Vet Med Educ. 2016;43(1):71–9. 10.3138/jvme.0315-034R1.
26. Lemos J, Hernandez A, Soto-Romero G. An Instrumented Glove to Assess Manual Dexterity in Simulation-Based Neurosurgical Education. Sensors. 2017;17:988. 10.3390/s17050988.

27. Kolozsvari NO, Feldman LS, Vassiliou MC, Demyttenaere S, Hoover ML. Sim one, do one, teach one: considerations in designing training curricula for surgical simulation. J Surg Educ. 2011;68:421–7. 10.1016/j.jsurg.2011.03.010.
28. Hirsch ED Jr. The Core Knowledge Curriculum–What's behind Its Success? Educational Leadersh. 1993;50:23–5.
29. Tsuda S, Scott D, Doyle J, Jones DB. Surgical skills training and simulation. Curr Probl Surg. 2009;46:271–370. 10.1067/j.cpsurg.2008.12.003.
30. Martin JA, Regehr G, Reznick R, Macrae H, Murnaghan J, Hutchison C, Brown M. Objective structured assessment of technical skill (OSATS) for surgical residents. Br J Surg. 1997;84:273–8. 10.1046/j.1365-2168.1997.02502.x.
31. Choy I, Okrainec A. Simulation in Surgery: Perfecting the Practice. Surg Clin North Am. 2010;90:457–73. 10.1016/j.suc.2010.02.011.
32. Vassiliou MC, Feldman LS, Andrew CG, Bergman S, Leffondré K, Stanbridge D, Fried GM. A global assessment tool for evaluation of intraoperative laparoscopic skills. Am J Surg. 2005;190:107–13. 10.1016/j.amjsurg.2005.04.004.
33. Fransson BA, Ragle CA, Mickas MM, Martin KW, Karn KNL. Ability to Perform Laparoscopic Intra- and Extracorporeal Suture Ligations in a Live Canine Ovariectomy Model after Simulation Training. J Vet Med Educ. 2022;25:e20210143. 10.3138/jvme-2021-0143.
34. Varas J, Mejía R, Riquelme A, Maluenda F, Buckel E, Salinas J, Martínez J, Aggarwal R, Jarufe N, Boza C. Significant transfer of surgical skills obtained with an advanced laparoscopic training program to a laparoscopic jejunojejunostomy in a live porcine model: feasibility of learning advanced laparoscopy in a general surgery residency. Surg Endosc. 2012;26:3486–94. 10.1007/s00464-012-2391-4.
35. Gallagher AG, Ritter EM, Champion H, Higgins G, Fried MP, Moses G, Smith CD, Satava RM. Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. Ann Surg. 2005;241:364–72. 10.1097/01.sla.0000151982.85062.80.
36. Spah CE, Elkins AD, Wehrenberg A, Jaffe MH, Baird DK, Naughton JF, Payton ME. Evaluation of two novel self-anchoring barbed sutures in a prophylactic laparoscopic gastropexy compared with intracorporeal tied knots: Laparoscopic Incisional Gastropexy With Novel Self-Anchoring Barbed Sutures. Vet Surg. 2013;42:932–42. 10.1111/j.1532-950X.2013.12043.x.
37. Binkley J, Bukoski AD, Doty J, Crane M, Barnes SL, Quick JA. Surgical Simulation: Markers of Proficiency. J Surg Educ. 2019;76:234–41. 10.1016/j.jsurg.2018.05.018.
38. Urbanová L, Crha M, Raušer P, Nečas A. Clinical results and complications of preventive laparoscopic assisted gastropexy in 17 dogs: preliminary study. Acta Vet Brno. 2011;80:93–9.
39. Hardie RJ, Flanders JA, Schmidt P, Credille KM, Pedrick TP, Short CE. Biomechanical and Histological Evaluation of a Laparoscopic Stapled Gastropexy Technique in Dogs. Vet Surg. 1996;25:127–33. 10.1111/j.1532-950x.1996.tb01388.x.

Tables

Table 1. Results of an advanced laparoscopic training program for pure laparoscopic gastropexy on the 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 and B with Wilcoxon. $^{BC, BD, DC}$ *P* values were obtained when comparing between columns evaluated by the Mann-Whitney U test. Operating time (Seconds), Total Movements (#), Total Smoothness in movements (#), and Total angular displacement (Degrees).

Table 2. Results obtained when performing TLG final evaluation on the simulator compared to the live pig model.

		Experimental group final evaluation of simulator	Experimental group final in vivo porcine model	p-value*
Anclaje	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 in 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
Corte	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 in 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
Sutura Lateral (Final) vs.	Operating time	650,8 (610,8-735,8)	1539 (1171,3-1768,3)	**0.001**
Sutura barbada (pig)	Total movements	742,5 (668,3-799,5)	1560, 7 (1183,8-1865,8)	**0.001**
	Smoothness in movements	0,313 (0,288-0,328)	0,307 (0,303-0,325)	0.741
	Total angular displacement	25049,3 (21966,7-28839,8)	49371 (36413,7-62446)	**0.001**
Sutura Medial (final) vs. Sutura barbada (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)	49371 (36413,7-62447)	**0.001**

* Mann-Whitney U test. Operating Time (Seconds), Total Movements (#), Total Smoothness in movements (#), Total Angular Displacement (Degrees)

Table 3. Microscopic findings in postmortem samples from the gastropexy site at three months post-TLG.

	F1			F2			F3			F4			F5			M1			M2			M3			M4			M5	M6
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**
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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: Absence; 2: Mild; 3: Mild to moderate; 4: Moderate; 5: Moderate to severe.

Table 4. Histopathological diagnosis of macroscopic fragments taken from the gastropexy site at four months post-TLG.

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).	

Figures

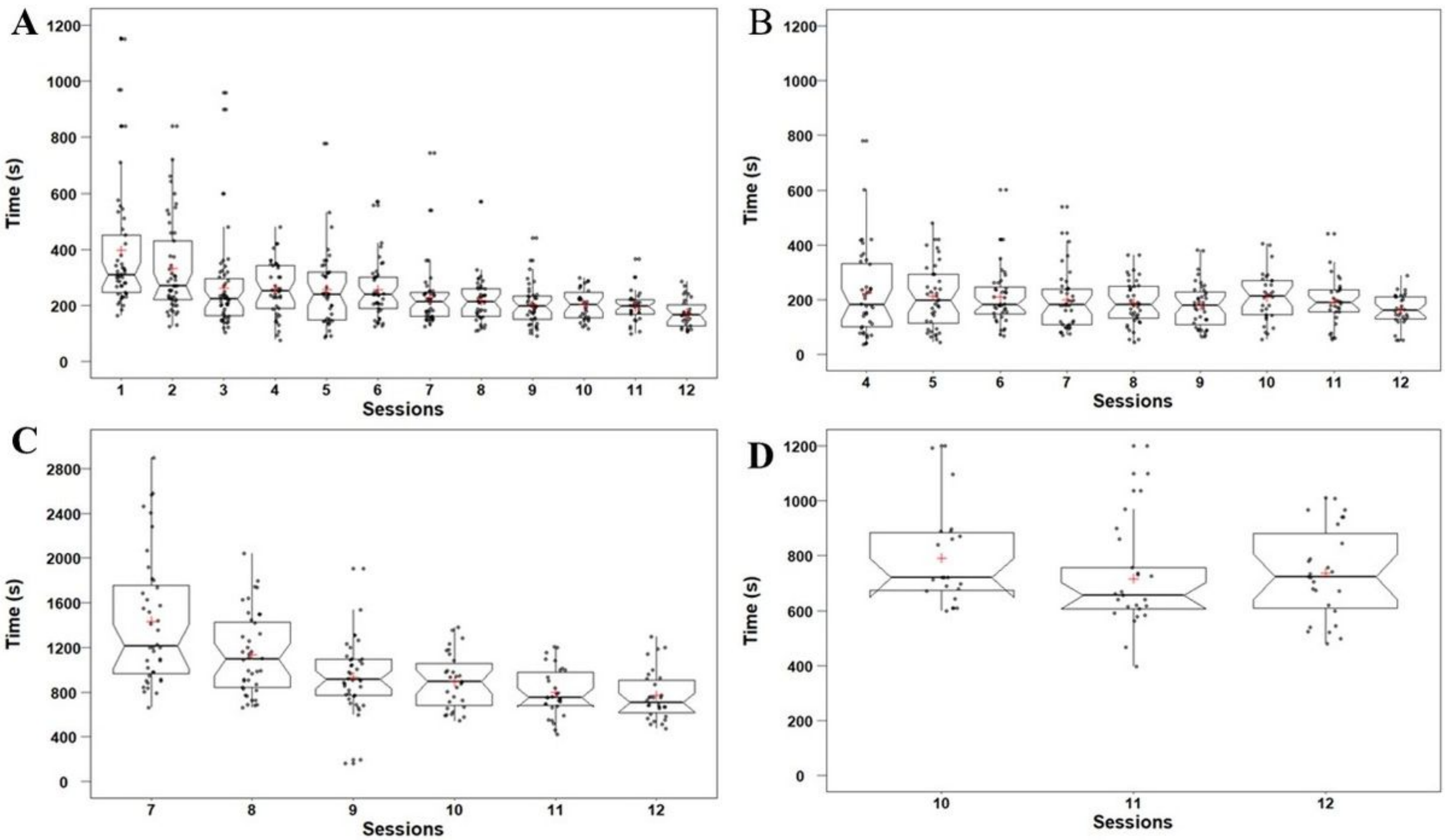

Figure 1

The learning curve is based on the time to complete each of the four tasks. A. anchoring, B. cutting, C. suturing the anterior or lateral aspect, D. suturing the posterior or medial aspect during the training sessions.

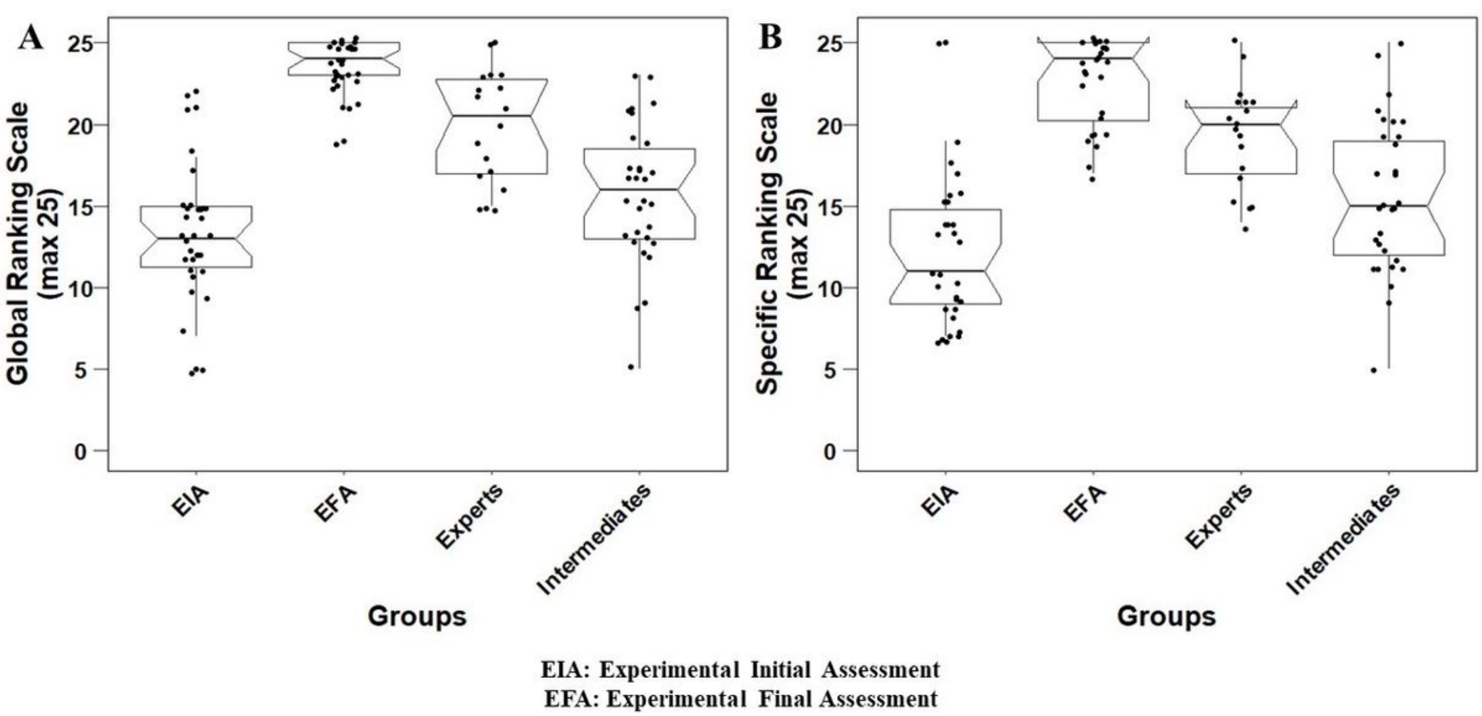

Figure 2

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.

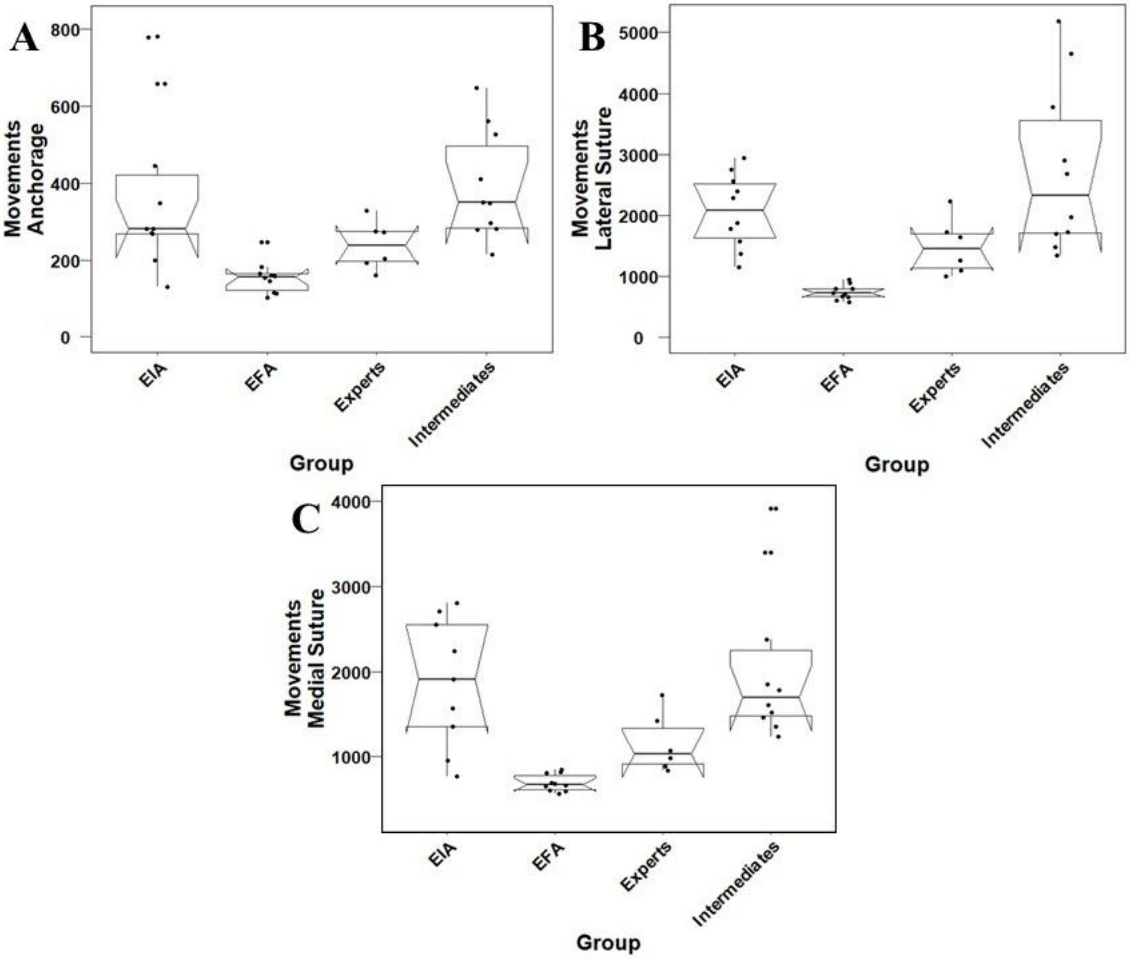

Figure 3

Box-and-whisker plot for evaluating the number of movements in the anchoring and suturing exercises taken with the HMAS.

Figure 4

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 of the pyloric antrum to the abdominal wall with a percutaneous suture. **C**. Cauterization and cutting of the seromuscular walls of the stomach and abdominal wall of approximately 4cm. **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.

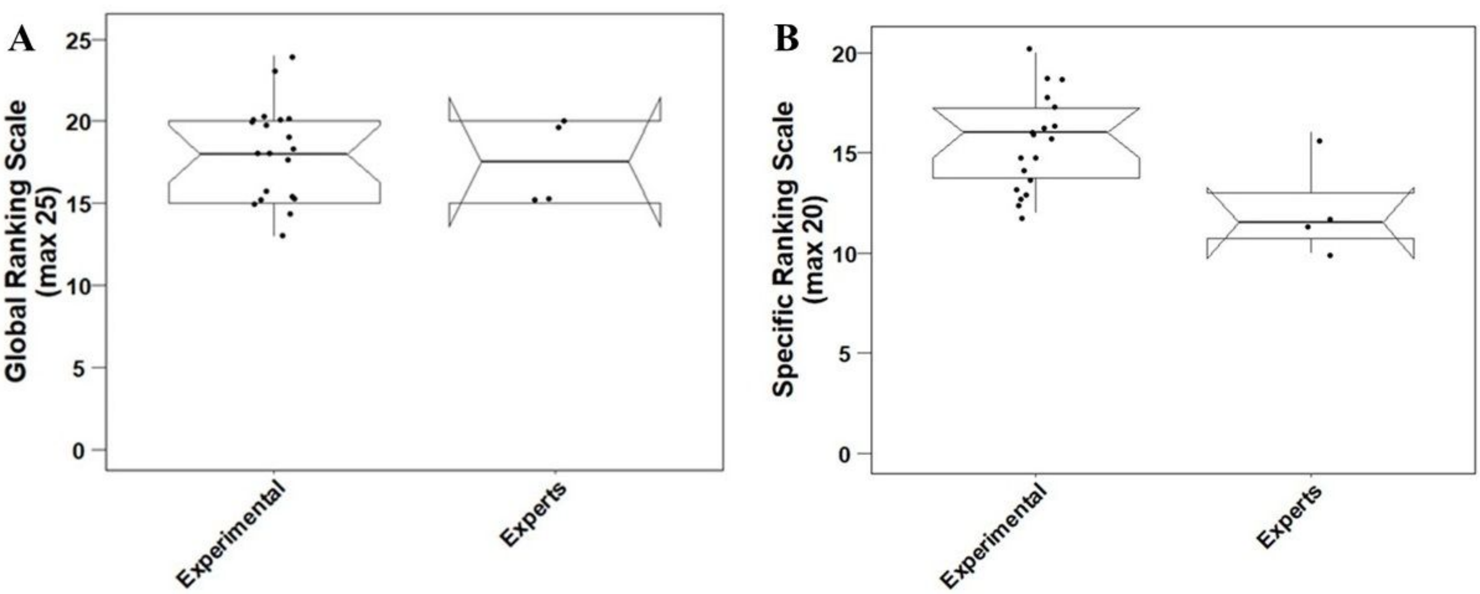

Figure 5

Box-and-whisker plot for evaluation with GOALS and SRS scales on the in vivo swine model.

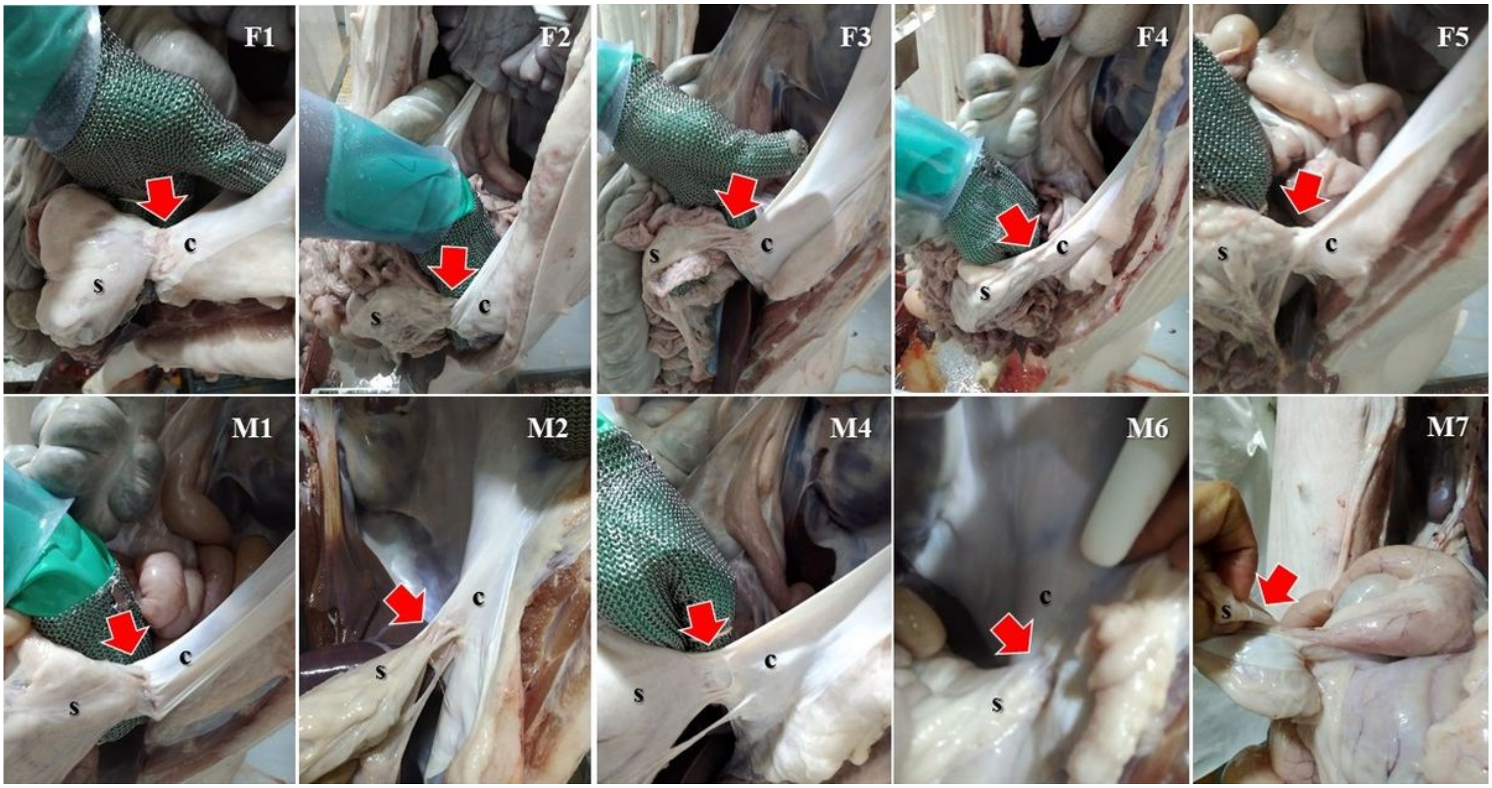

Figure 6

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

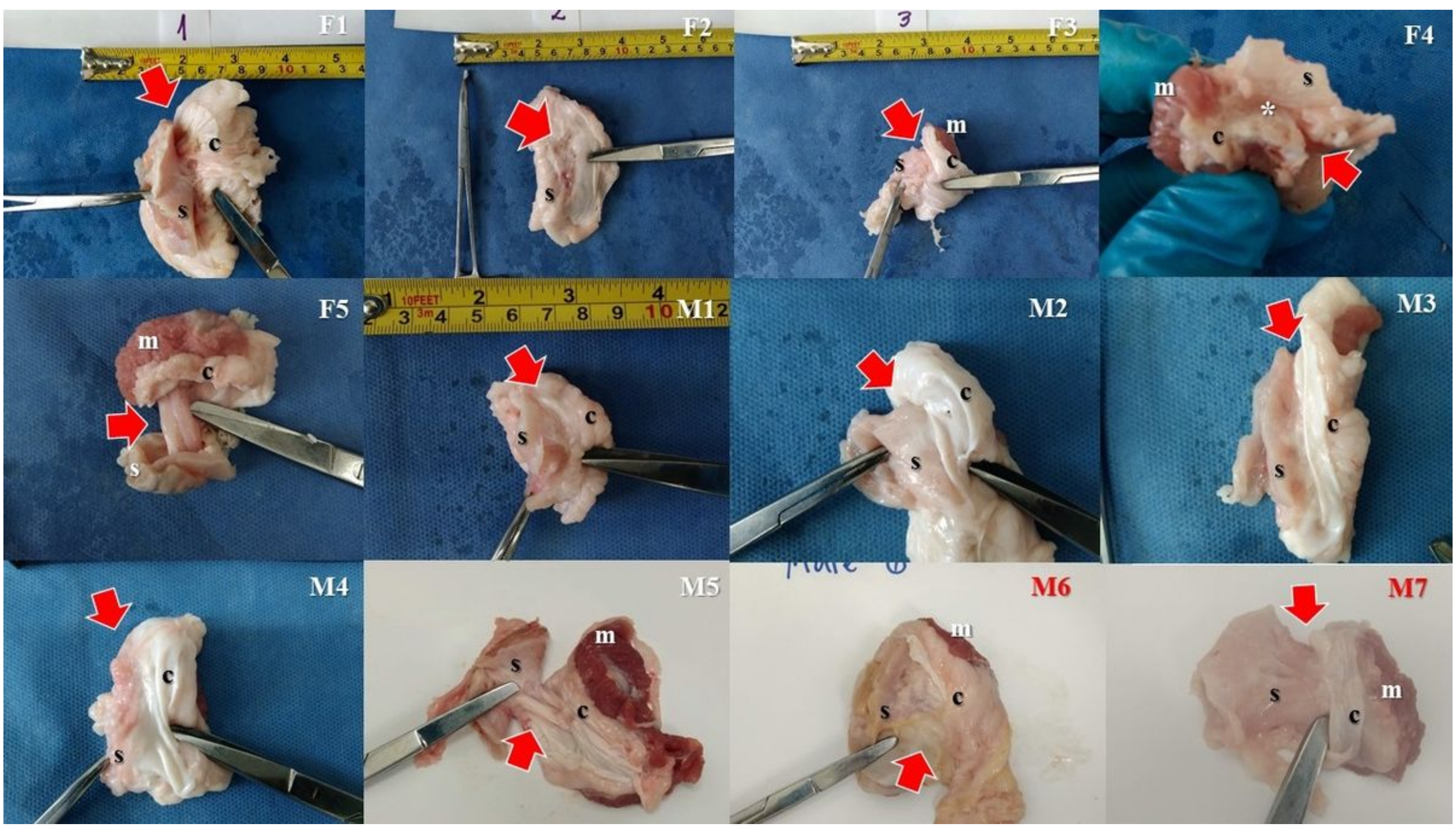

Figure 7

Macroscopic aspect of gastropexy samples of five females (F1 to F5) and seven males (M1, M2, M4, M6, and 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) probably corresponds to the Rectus abdominal muscle.

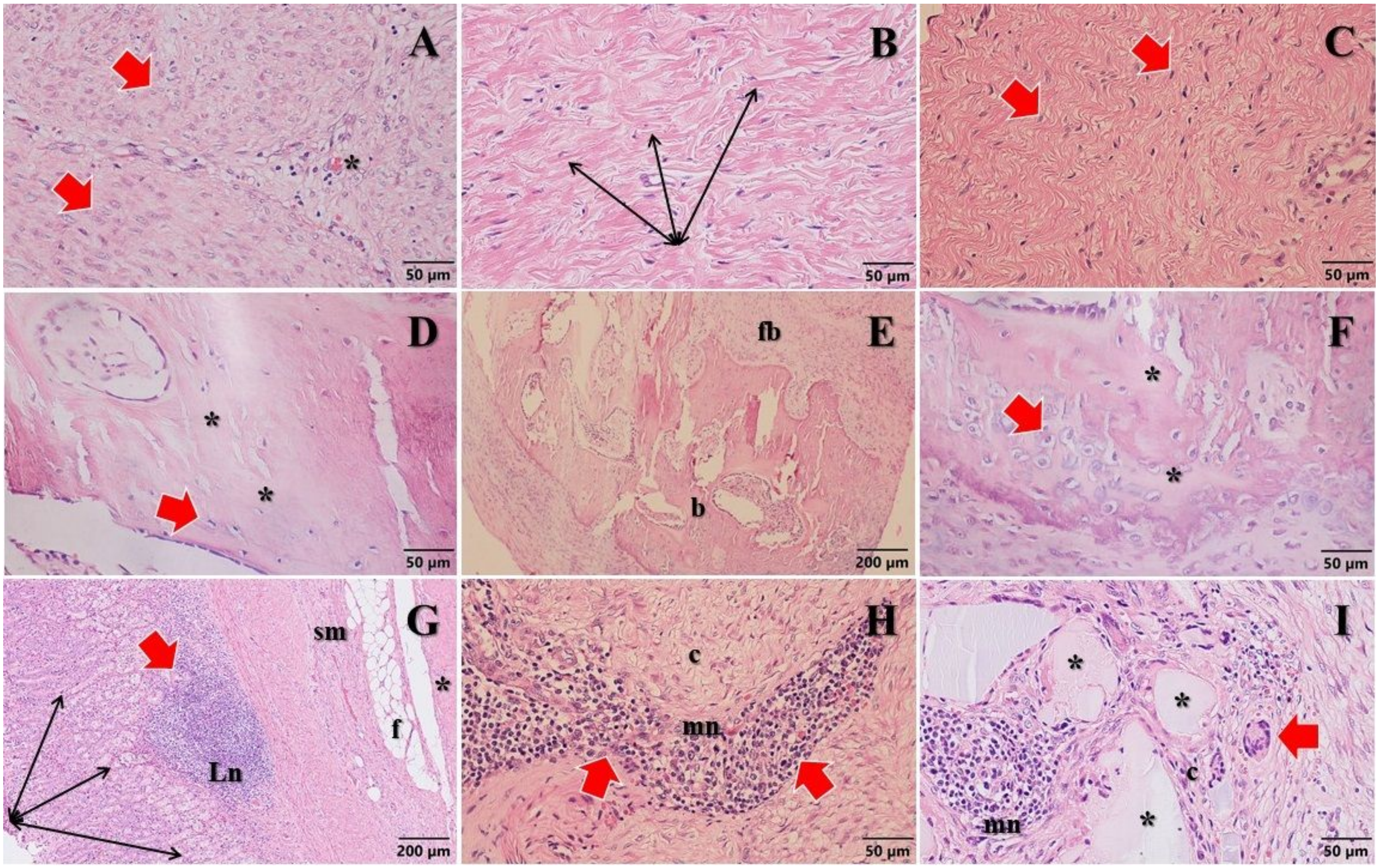

Figure 8

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) that has predominantly 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).

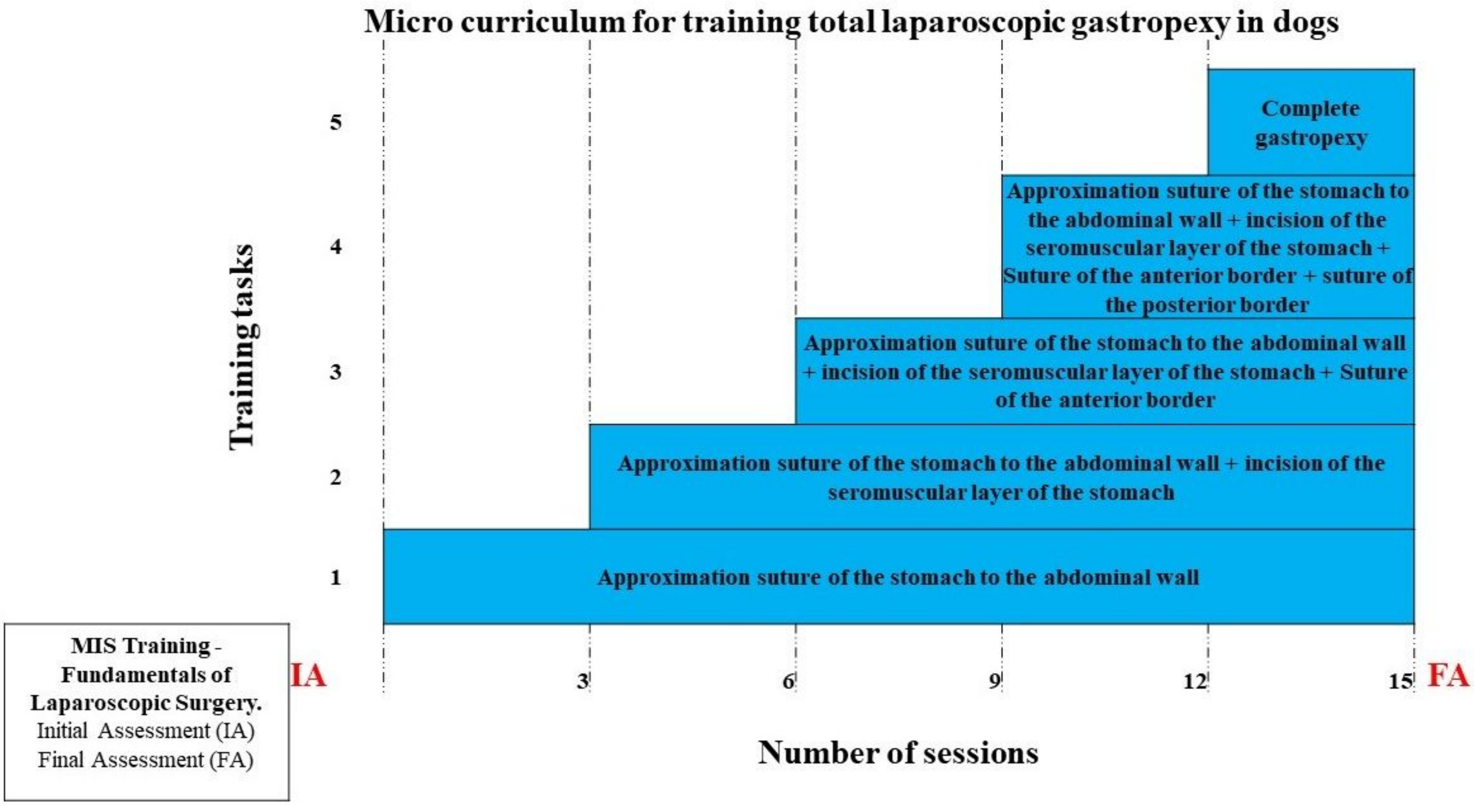

Figure 9

The curriculum of the advanced training program.

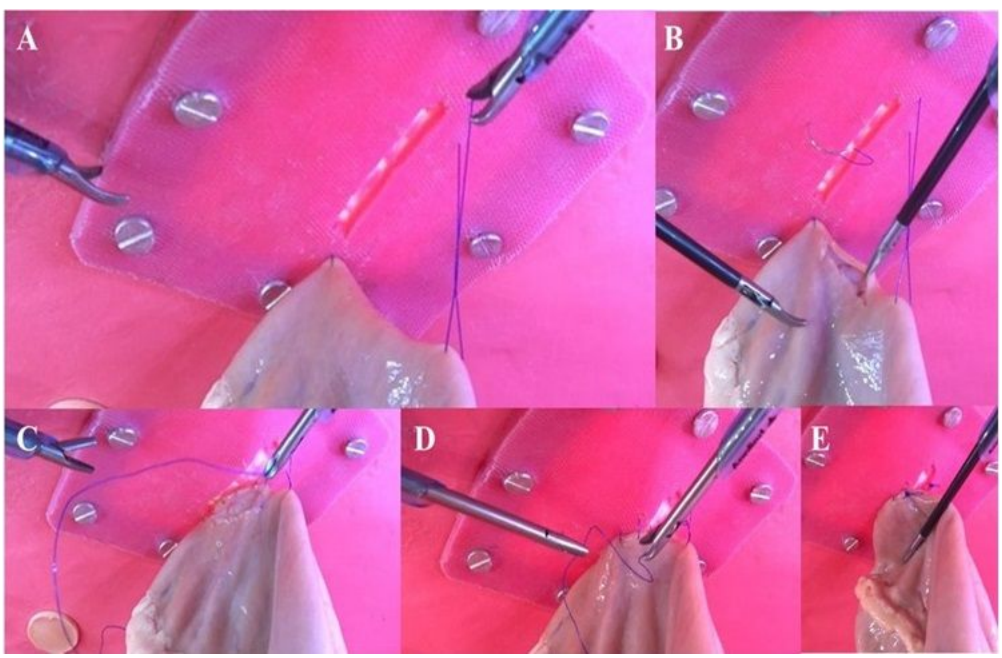

Figure 10

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.