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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

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Abstract

Background Simulation may provide a solution to acquire advanced laparoscopic skills, thereby completing the curriculum of residency programs in general surgery. This study was designed to present an advanced simulation-training program and to assess the transfer of skills to a live porcine model.

Methods First-year residents were assessed in a 14-session advanced laparoscopic training program followed by performing a jejunojejunostomy in a live porcine model. Previous and after training assessments at the bench model were compared to a single performance of six expert laparoscopic surgeons. Results obtained by trainees at the porcine model assessment were compared to those of 11 general surgeons without any laparoscopic lab-simulation training and 6 expert laparoscopic surgeons. In all assessments, global and specific OSATS scores, operative time, and covered path length of hands were registered.

Results Twenty-five residents improved significantly their global and specific OSATS score median at the bench model [7 (range, 6–11) vs. 23 (range, 21–24); $p < 0.05$ and 7 (range, 4–8) vs. 18 (range, 18–19); $p < 0.05$, respectively] and obtained significantly better scores on the porcine model compared with general surgeons with no lab-simulation training [21 (range, 20.5–21) vs. 8 (range, 12–14); $p < 0.05$]. The results were comparable to those achieved by expert certificated bariatric surgeons. Total path lengths registered for trainees were more efficient post-training and significantly lower compared with general surgeons on the porcine model [7 (range, 6–11) vs. 23 (range, 21–24); $p < 0.05$] with no statistical difference compared with experts.

Conclusions Trainees significantly improved their advanced laparoscopic skills to a level compared with expert surgeons. More importantly, these acquired skills were transferred to a more complex live model.

Keywords Training/courses · Simulation · Advanced laparoscopy · Education · Laparoscopic training · Surgery

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The vast majority of surgical residency programs in the world are performed based on compliance with traditional curricula [1, 2]. These set of courses are time-consuming and distributed among 3–5 years depending on the training center. In a traditional surgical residency program, residents rotate through different clinical specialties, such as gastrointestinal surgery, urology, surgical oncology, and plastic surgery. Their competency is achieved by what they are able to observe through a mentorship model and what they are assessed at examinations [1–3]. Other programs have an outcome-based curriculum, allowing residents to acquire the core knowledge, skills, and attitudes according to their level. At the same time, it is expected from residents to acquire the surgical skills that will allow them to operate on patients once they graduate [1, 3]. However, the current model cannot ensure that after 3 or 5 years of residency a graduated surgeon from a program with traditional curriculum will have the necessary surgical skills to cope with complex procedures [1]. On the other hand, legislation regarding resident working hours, the high institutional costs involved in student formation, along with the need to provide safety care to the patient has led to a significant reduction in operative exposure [2, 4–6]. Furthermore, the growing need to instruct residents in difficult minimally invasive techniques, such as laparoscopy, in addition to traditional surgery makes it even harder to achieve a 3- to 5-year curriculum that guarantees proficient residents [7, 8]. Simulation programs offer a solution to the mentioned problems by allowing a safe and efficient environment to acquire the desired surgical skills [2, 6, 9].

Nowadays, most residency programs that have an established simulation curriculum for training laparoscopy are teaching basic skills techniques to trainees to acquire the minimum dexterity necessary to accomplish a simple procedure, such as an appendectomy or cholecystectomy [6]. Programs, such as the fundamentals of laparoscopic surgery (FLS), are a prerequisite for every graduating surgical resident in the United States [10]. To achieve advanced laparoscopic skills, there is a necessity for setting-up new validated simulation programs that can ensure trainees the desired technical level of expertise [6, 11].

The purpose of this study was to propose a structured simulated training program designed to obtain advanced laparoscopic skills, explaining in details the methodology required to achieve the desired technique, its validation, and the subsequent transfer of the acquired skills to a more complex scenario: a live porcine model.

Methods

Stage A: advanced laparoscopic training program

First-year residents (PGY1) from the postgraduate training programs of general surgery, gynecology, and orthopedics at the Pontificia Universidad Católica de Chile Medical School, whom already completed a validated basic laparoscopic training curriculum that includes Laparoscopic Virtual Reality in addition to the FLS course [10, 12], underwent a systematic competency-based laparoscopic training program to improve their advanced laparoscopic surgical skills. The objective of the program was to prepare residents to acquire the skills necessary to perform a complete two-layer handsewn jejunojejunostomy (JJO).

Initial assessment (IA)

Before initiating their training, residents were gathered at a master class where they were taught how to perform a laparoscopic JJO without using any stapler device [13]. In addition, a digital versatile disc (DVD) was provided to each student with a step-by-step instructional video-guide emphasizing the key issues related to the procedure and most common mistakes.

After the introductory class, residents were assessed performing a handsewn JJO on an ex vivo small bowel (bovine intestine) in a modified validated bench model [14]. Each task was video recorded and assessed by two blinded experts, bariatric surgeons, using a validated global and a modified specific rating scales for objective structured assessment of technical skills (OSATS) [14, 15]. Interrater reliability was tested by calculating Kappa coefficient (0–1) [16, 17]. In addition, outcomes, such as operative time, leakage, and permeability of the JJO, were assessed. Each student had 60 min maximum time to complete the procedure. These results were considered as a baseline performance previous to the advanced laparoscopic training program.

Economy of movements was assessed using the Imperial College Surgical Assessment Device (ICSAD) allowing objective quantification of movements and traveled path length of each hand (distance measured in meters) [18, 19].

Training sessions

Once assessed, trainees were enrolled in a 14-sessions training program. The curriculum was designed as a progressive cumulative experience; each trainee learned a specific task, repeated it, received effective feedback to achieve proficiency [20], and then a new task was added, which obliged the student to continue repeating the first task through the 14 sessions reinforcing and consolidating the acquired skills. This curriculum program is an expression of the constructivist approach in which new knowledge builds on prior core knowledge [21] (Fig. 1). The program was focused on common mistakes and important limiting aspects, such as intracorporeal suturing.

Every session was supervised by a laparoscopic expert trainer who measured each student‘s performance using global and modified specific OSATS scales [14, 15]. The expert also recorded the time taken for each task. Using this information, the trainer was responsible for giving personalized effective feedback at the end of each session, including the trainee’s strengths and weaknesses and how to improve their performance in the next session [20]. Before the sessions, a step-by-step video content was delivered to each trainee, explaining in detail how to accomplish every task.

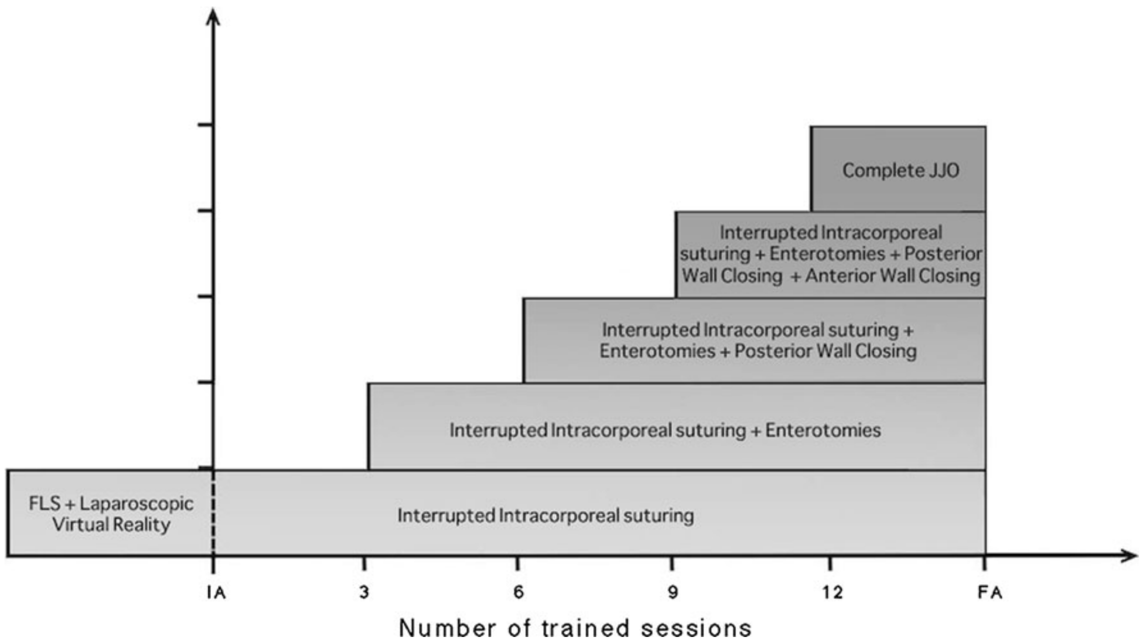

Fig. 1 Design of the advanced laparoscopic training program. *IA* initial assessment; *FA* final assessment; *FLS* fundamentals of laparoscopic surgery; *JJO* jejunojejunostomy

The surgical technique included the following aspects:

1. Interrupted intracorporeal suturing for intestinal loop approach: each resident had to perform three intracorporeal stitches to approach two limbs of bovine intestinal bowel. The trainer delivered effective feedback after the first three stitches. The trainee had to repeat this task and record the time spent for every group of three stitches.
2. Enterotomies using ultrasonic energy device: each trainee had to perform an enterotomy on both approached intestinal limbs. The trainer delivered effective feedback after observing the trainee performing the first pair of enterotomies. The trainee repeated this task and recorded the time spent for every pair of enterotomies.
3. JJO posterior wall closing using a handsewn running suture technique: residents had to perform an intracorporeal running suture posterior wall closing. The trainer delivered effective feedback after the first posterior wall closing. The trainee had to repeat this task and record the time spent for every posterior wall closing.
4. JJO anterior wall closing using a hand sewn running suture technique: residents had to perform an intracorporeal running suture anterior wall closing. The trainer delivered effective feedback after the first anterior wall closing. The trainee had to repeat this task and record the time spent for every anterior wall closing.

To standardize the time spent on each training session to a 1-h period allowing the adaptation of the constructivist approach [21], the sessions were designed as follows (Fig. 1): Interrupted intracorporeal suturing was performed in every session where a minimum of five groups of three stitches was required in the first six sessions, four in the 7th to 9th, and three groups between the 10th and 12th session. Enterotomies were added from the 4th session and so on, next to each group of stitches. Posterior wall closing was added from the 7th session and so on, merging the previously performed enterotomies. Anterior wall closing was added from the 10th session and so on, completing the anastomosis initiated with each posterior wall closing. The last two sessions (13th and 14th) consisted of performing the whole JJO for three times recording the respective time.

Final assessment (FA)

At the end of the training program, all residents were reassessed under the same standards of the IA. However, this time each student had 20 min to accomplish the full task. Additionally, all results were compared to those achieved by certificated bariatric surgeons performing the same procedure on the same bench model. The Pontificia Universidad Católica de Chile Medical School for Bariatric Surgery has been designated as a Center of Excellence in Bariatric Surgery, where certification of at least 125 bariatric surgical cases in the preceding 12-month period was accomplished. In the year 2010, more than 275 laparoscopic Roux-en-Y gastric bypass (LRYGB) surgeries were completed at our institution, ensuring the expertise of each surgeon recruited in this experimental protocol.

Proficiency criteria

Angoff standard-setting point for Global and Specific OSATS score was set at 21 points (out of 25, equivalent to 84 %) and 18 points (out of 20, equivalent to 90 %) respectively [17]. It was stated previous training that if a resident did not approved the cutoff score, he had to continue training under direct supervision of the trainer until proficiency was acquired. The observations of each personal learning curve were considered previous approving the training program.

Stage B: JJO using a stapling device on a live porcine model

Training with stapler devices

The surgical residents trainees were gathered once again for a master class [13], this time to learn how to perform a JJO with the use of a Linear (Blue) stapler device (ETHICON® Johnson & Johnson, Cincinnati, OH, ENDO-SURGERY ETS-FLEX 45 mm) as described by Higa et al. [22] for the JJO of a LRYGB. A DVD was provided with a step-by-step instructional video-guide describing the procedure and a comparison of how to perform a stapled JJO on both the bench model endotrainer and on the live porcine model. Trainees had to practice the stapled JJO on the bench model without firing but, instead, mimicking the act of using the stapler device under expert supervision for two additional sessions.

Live porcine assessment

Residents were then assessed executing the JJO on a live porcine model. All animal experiments had the approval of our institutional ethics committee. The results of the experimental group were compared to a control group, composed by general surgeons graduated from traditional residency programs of our country without any simulation-training program and certified bariatric surgeons executing the same procedure.

Statistical analysis

Data were analyzed with the Statistical Package for the Social Sciences version 15.0 (SPSS, Inc., Chicago, IL) using nonparametric tests. For stage A and B statistical analysis, Mann–Whitney and Kruskal–Wallis tests were used to compare each specific nonparametric variable within each group, and the results were exposed in median (Q1–Q3). Wilcoxon test was used for pre-post assessment. $p < 0.05$ was considered statistically significant.

Results

Stage A: advanced laparoscopic training program

Initial assessment

Twenty-five residents (PGY1) who had approved our basic laparoscopic curriculum (9 surgical residents, 9 gynecologist, and 7 orthopedics) were gathered at the master class and subsequently assessed performing a handsewn JJO on a bench model to obtain baseline scores before starting the simulated advanced laparoscopic training program. Results of global and specific rating scores, total path lengths (TPL) measured with ICSAD, operative time, and percentage of residents who had initial leakage and permeability of the JJO are shown in Table 1. There was no statistically significant difference between the scores of the different surgical specialty programs.

Training sessions

All 25 residents completed the 14 sessions within a period of 110 days (100 % follow-up). After the 14 sessions, all residents passed the Angoff standard-setting point for Global and Specific OSATS. All training periods were scheduled between the laparoscopic expert trainer, laboratory staff members, and each resident. The median time taken for each session was of 65 (range, 39–122) minutes.

The expert trainer measured each student's performance on every session, using the same global and modified specific OSATS scales administered in the IA, and registered the time taken for each exercise. Results were plotted into learning curve graphs (Fig. 2A, B). From session 12 forward, no significant variance was observed in the progression of the group's global OSATS median score. The expert trainer perceived that effective feedback was more necessary through the first four sessions and at the beginning of every new task added to the training.

Final assessment

Once a trainee concluded the 14 sessions, their performance was measured under a FA using the same standards as for the IA. The obtained results were compared to those achieved by six experts (certificated bariatric surgeons) performing the same procedure under equal conditions on the bench model. The comparison between the results obtained in the IA, the FA, and the expert's performance are shown in Table 1 and Fig. 3A, B. Residents improved significantly their global and specific OSATS score median: 7 (range, 6–11) vs. 23 (range, 21–24); $p < 0.05$ and 7 (range, 4–8) vs. 18 (range, 18–19); $p < 0.05$, respectively. The TPL covered by both hands, registered with ICSAD, diminished significantly

Table 1 Trainees results obtained at the advanced laparoscopic training program (bench model)

	^{A}IA ($n = 25$)	^{B}FA ($n = 25$)	^{C}Experts ($n = 6$)	^{AB}p value	^{BC}p value
GRS (5–25)	7 (6–11)	23 (21–24)	24 (23–25)	<0.01	0.013
SRS (4–20)	7 (5–8)	18 (18–19)	19 (18–19)	<0.01	0.225
Operative time (m)	43.5 (33–51)	18.5 (17–19)	12 (11–12)	<0.01	<0.01
% Permeable anastomosis with no leak	12 %	100 %	100 %	<0.01	
TPL (m)	307 (265–380)	118 (110–130)	78.63 (73–80)	<0.01	0.03

^{AB} p values obtained when comparing columns ^{A} and ^{B} with Wilcoxon matched-pairs test

^{BC} p values obtained when comparing columns ^{B} and ^{C} with Mann–Whitney

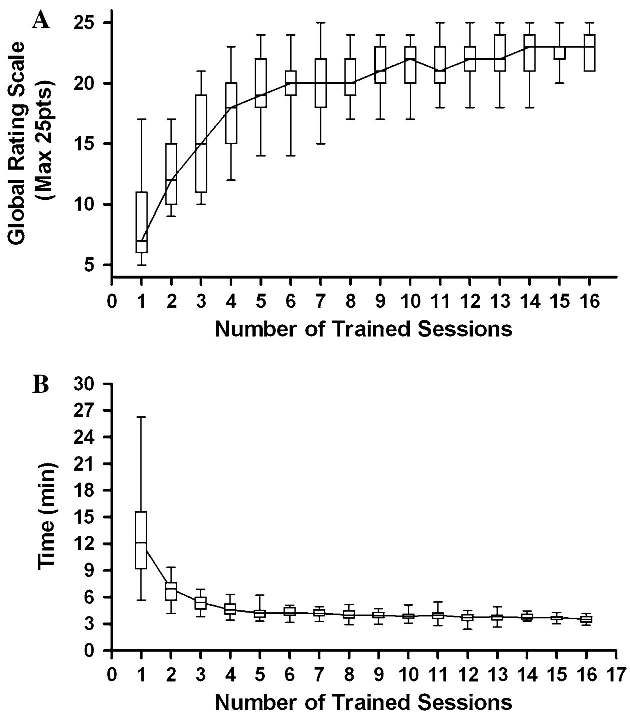

Fig. 2 Learning curves. **A** Learning curve achieved by trainees (PGY1), based on the global rating scores obtained in each session (median Q1–Q3) of the advanced laparoscopic training program. Sessions 1 and 16 correspond to the initial and final assessments respectively. **B** Learning curve achieved by trainees based on the time taken to complete three interrupted intracorporeal stitches

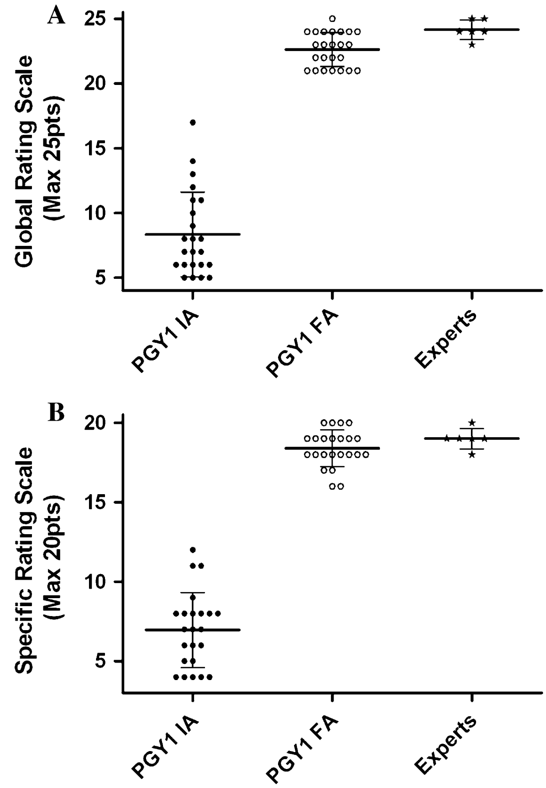

Fig. 3 **A** Global and **B** specific rating OSATS scores obtained by residents before and after the advanced laparoscopic training program, compared to the score obtained by experts (median Q1–Q3)

from the IA to post-training [307 (range, 265–380) vs. 118 (range, 110–130); $p < 0.05$], obtaining closer results to the achieved by experts (Table 1; Fig. 4).

Stage B: JJO using a stapling device on a live porcine model

Training with stapler devices

From the 25 trained residents, 9 surgical residents were taught how to perform a JJO, this time with a stapler device. In the two given sessions for training, trainees easily managed the technique at the bench model and obtained excellent global and specific OSATS scores (results not shown).

Live porcine assessment

The nine PGY1 surgical residents were assessed executing a stapled JJO on a live porcine model and compared to a control group, consisting of 11 general surgeons graduated from traditional residency programs of our country without any lab-simulation training and six certified bariatric surgeons executing the same procedure. Trainees' results obtained with global and specific OSATS were significantly better compared with those of general surgeons

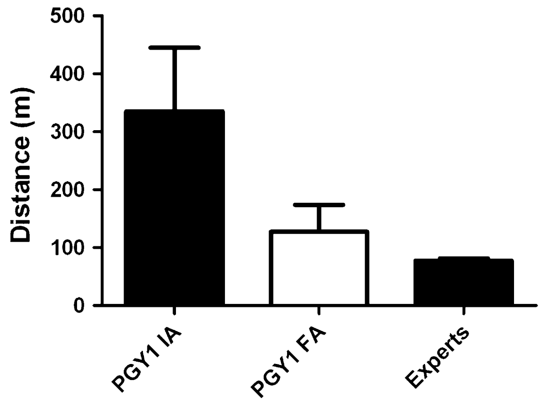

Fig. 4 TPL covered by both hands of first-year residents (PGY1) at the IA and post-training FA of the advanced laparoscopic training program and compared to the TPL obtained by experts

($p < 0.01$) and comparable to those achieved by experts ($p = 0.365$; Table 2; Fig. 5A, B). TPLs registered for trainees were significantly lower compared with general surgeons [112m (range, 90–129) vs. 548m (range, 373–625); $p < 0.01$] and with no statistical difference compared with experts ($p = 0.299$; Table 2; Fig. 6). Residents' operative times (in minutes) were faster than general surgeons but slower than experts (Table 2).

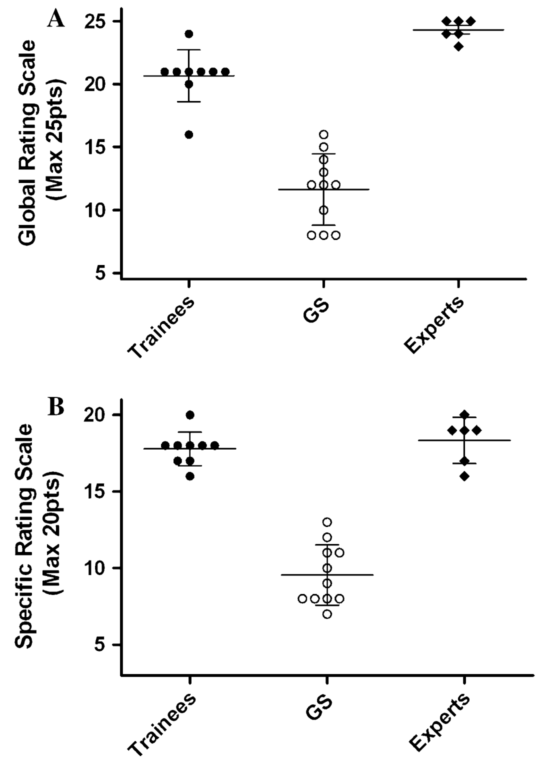

Fig. 5 **A** Global and **B** specific rating OSATS scores obtained by trained residents (PGY1), general surgeons (GS without lab-simulation training), and experts, when performing a stapled JJO in a live porcine model

Discussion

This study proposes a feasible-to-apply advanced laparoscopic training program that can be easily incorporated to any residency program with laparoscopic simulation. Moreover, the baseline skills required for performing the complete advanced training program are most validated basic laparoscopic programs, such as the FLS or virtual reality training curricula [10, 12, 23]. To have a validated basic laparoscopic curriculum as a baseline may ensure the success of the advanced laparoscopic training program that incorporates the acquisition of high-level techniques and at the same time adds continuity to competency-based training. Our study incorporates most strategies to obtain a validated simulation program, such as IA with a previous master class [13], blinded initial and FAs [16], the incorporation of validated OSATS [14, 15, 24, 25], motion tracking devices [18, 19], a modified validated bench model [14] and training sessions with effective feedback [20, 26].

In the IA, a great variability among all residents' global and specific rating OSATS scores was observed. In addition, the median score had a marked asymmetry accusing a great heterogeneity within the whole group. Due to the constant effective feedback in each training session, residents rapidly learned how to overcome their mistakes, obtaining better scores. Thus, the variability and median asymmetry diminished toward the eighth session as observed on the learning curve. Providing effective feedback during the training process was one of the most important issues to enhance the

Table 2 Live porcine model assessment, comparison between trainees, general surgeons with no simulated lab training, and expert certified bariatric surgeons

	[A]Trainees ($n = 9$)	[B]General surgeons ($n = 11$)	[C]Experts ($n = 6$)	[AB]p value	[AC]p value
GRS (5–25)	21 (20.5–21)	8 (12–14)	24.5 (24–25)	<0.01	<0.01
SRS (4–20)	18 (17–18)	8 (9–11)	19 (17–19)	<0.01	0.365
Operative time (min)	18 (16–21)	23 (20–28)	9 (7–10)	<0.05	<0.01
TPL (m)	112 (90–129)	548 (373–625)	63 (54–137)	<0.01	0.299

[AB] p values obtained when comparing columns [A] and [B] with Mann–Whitney test

[AC] p values obtained when comparing columns [A] and [C] with Mann–Whitney test

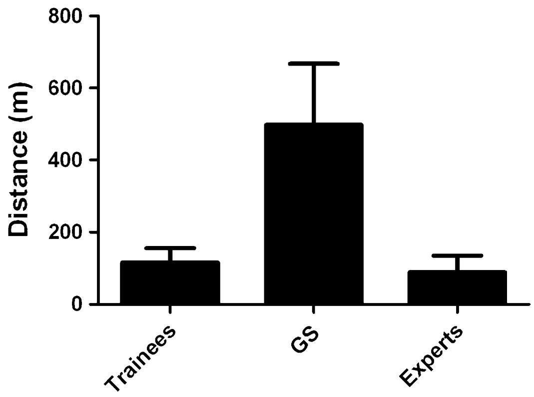

Fig. 6 TPL covered by both hands of trainees, general surgeons (GS), without lab-simulation training, and experts, when performing a JJO in a live porcine model

trainees "learning curve"; this training instrument is highly supported in educational medicine [20, 26]. However, to be able to have an expert delivering effective feedback on each session is expensive and not always possible. As mentioned in the results, the expert trainer perceived that effective feedback was more necessary for the first four sessions and at the beginning of every new task added to the training. If we can restrict the effective feedback for when it is strictly necessary, it is feasible and cost-effective to incorporate this education tool at every lab-simulation training program. By the end of session 12, the complete group was technically homogeneous and had improved their global and specific scores significantly. The training was not stopped at this stage, even after observing that the learning curve showed no significant variance, to reinforce for at least three sessions what was learned.

An advantage of using the constructivism approach [21] in our program was focusing on key detailed technical aspects during the first sessions, such as intracorporeal suturing, instead of allowing trainees to perform the complete JJO from the beginning, which would have spent their limited time on a general exercise. For the expert supervisor, it was easier to improve specific mistakes rather than revising every general aspect of the JJO. It is worth noting that all residents performed a functional, without leakage anastomosis in less than 20 min, justifying that when the correct techniques are learned in a step-wise manner and earnestly trained, the complete procedure can still be achieved. The median time taken for each session was of 65 min, time that can easily be protected and fixed to any residency program. In our institution from the year 2010, all surgical, gynecologist, and orthopedics residents have protected and obligatory time for training.

To assess the advanced laparoscopic training program effectiveness according to Kirkpatrick's four-level model [27, 28], it is important to address all four levels in order:

Level 1: *Reaction* A seven-item questionnaire was constructed using a seven-point Likert scale to measure residents' perception of the training program (data not shown). The questionnaire was administered at the end of the post-training assessment to all residents who participated of the program. The results revealed an excellent perception of it, claiming to be 100 % satisfied with the methodology of the program, the simulation model, and its high fidelity, feedback quality and how feedback was delivered.

Level 2: *Learning* Residents improved significantly their advanced laparoscopic skills measured objectively with validated OSATS. In addition, trainees performed the complete JJO with better economy of movements. In other words, residents became faster and with the need of significantly less movements (measured with ICSAD) to accomplish every exercise with high standards. Moreover, expert certificated bariatric surgeons, who demonstrated concurrent validity by performing the JJO as experts at the bench model, had similar performance to that of trainees post-training.

Level 3: *Transfer* In surgical simulation, the major challenge has always been how to demonstrate that a simulation program actually works in the operating room (OR) [29]. Our study has no predictive validity to the OR. Nevertheless, the significantly better results achieved by PGY1 trainees compared with the control group of general surgeons without lab-simulation at the complex live porcine model suggest a high level of technical acquisition, which in our study, may be compared to the level demonstrated by experts on the same model. Most simulation training programs that have demonstrated predictive validity are based on basic laparoscopic technique objectives for residents to acquire and execute in the OR, such as the technical skills necessary for performing cholecystectomies, appendectomies, and sigmoidectomies [16, 29, 30]. However, laparoscopy has evolved to a standard where most procedures from traditional surgery are being performed with comparable results but with the advantages of minimally invasive surgery. Yet, the learning curves for these procedures are latent and dependent on the number of patients of each institution. On the other hand, in general surgery programs, it is expected for residents to be able to manage in open surgery most cases of technically advanced procedures, such as bowel anastomosis. These procedures should, when necessary and possible, be conducted with a laparoscopic approach. Consequently, there is a need for a validated advanced laparoscopic simulation training programs to upraise and, moreover, to demonstrate the transfer of the advanced skills acquired through training to the OR.

Level 4: *Dissemination value to the organization* The surgery division with the support of the postgraduate director of our medical school has invested in obtaining structured simulation training programs. A complete infrastructure installed right next to the main clinical hospital for trainees to reach under protected training time, in addition to exclusive personal and available staff members, a dedicated simulation research fellow, medical teachers who collaborate and research on educational assessment, and a simulation directory for task and goals decisions, allows a continuous growth related to the simulation area, offering residents the opportunity to learn under an objective structured residency program.

Conclusions

The advanced laparoscopic simulation-training program proposed in this study is effective and feasible to replicate in any simulation laboratory. The program allows trainees to improve significantly advanced laparoscopic skills at the lab; these acquired skills are transferred to more complex scenario with a level of performance comparable to expert laparoscopic surgeons.

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