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Simulation-trained junior residents perform better than general surgeons on advanced laparoscopic cases

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Abstract
Background Multiple simulation training programs have demonstrated that effective transfer of skills can be attained and applied into a more complex scenario, but evidence regarding transfer to the operating room is limited.
Objective To assess junior residents trained with simulation performing an advanced laparoscopic procedure in the OR and compare results to those of general surgeons without simulation training and expert laparoscopic surgeons.
Methods Experimental study: After a validated 16-session advanced laparoscopy simulation training program, junior trainees were compared to general surgeons (GS) with no simulation training and expert bariatric surgeons (BS) in performing a stapled jejuno-jejunostomy (JJO) in the OR. Global rating scale (GRS) and specific rating scale scores, operative time and the distance traveled by both hands measured with a tracking device, were assessed. In addition, all perioperative and immediate postoperative morbidities were registered.
Results Ten junior trainees, 12 GS and 5 BS experts were assessed performing a JJO in the OR. All trainees completed the entire JJO in the OR without any takeovers by the BS. Six (50 %) BS takeovers took place in the GS group. Trainees had significantly better results in all measured outcomes when compared to GS with considerable higher GRS median [19.5 (18.8–23.5) vs. 12 (9–13.8) $p < 0.001$] and lower operative time. One morbidity was registered; a patient in the trainees group was readmitted at postoperative day 10 for mechanical ileus that resolved with medical treatment.
Conclusion This study demonstrated transfer of advanced laparoscopic skills acquired through a simulated training program in novice surgical residents to the OR.

Keywords Simulation · Laparoscopic training · Surgical training · Advanced laparoscopy · Surgical simulation

Simulation-based learning is becoming widely established within medical education. In laparoscopic surgery, training programs have demonstrated acquisition of proficiency and transfer of basic and procedural skills to the operating room (OR) [1–6]. Currently, standardized basic simulated programs such as the Fundamentals of Laparoscopic Surgery (FLS) have been incorporated into training curricula and are a prerequisite for certification with the American Board of Surgery [7]. In advanced laparoscopic procedures, there is evidence for skills improvement after simulated training programs [3, 4, 8–10]. Nevertheless, the evidence regarding the transfer of acquired advanced laparoscopic skills to a more complex scenario is scarce [3, 11]. According to a recent systematic review about advanced training in

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laparoscopic surgery, higher-quality studies are required to appraise educational value to this field [11].

Our group has previously reported in surgical endoscopy the results of a structured simulated training program designed to obtain proficiency in advanced laparoscopic procedures in surgical residents [12]. All educational tools and concepts included in this program underwent thorough validation prior to their incorporation. These included theoretical master classes prior to training, blinded initial and final assessments, the incorporation of a validated global and specific rating scales, the use of a validated motion tracking device, training sessions with effective feedback, debriefing sessions and a systematic constructivist-based approach for task learning. We have demonstrated that the program allows trainees to improve significantly advanced laparoscopic skills in the laboratory and then transfer the acquired skills to a live porcine model with a level of performance comparable to expert laparoscopic surgeons and significantly better to those of general surgeons who graduated from traditional programs without laboratory simulation. Based on these findings, we believed trainees may outperform general surgeons with no laboratory simulation training in the OR on advanced laparoscopic live human cases.

The objective of the present study was to assess the effectiveness of this simulated advanced laparoscopic training program in the OR, by comparing junior trainees' performance to that of general surgeons from a traditional program without laboratory simulation training and to expert laparoscopic surgeons.

Materials and methods

This report is the final stage of an institutional study based on a systematic laparoscopic training program for novice general surgery residents (postgraduate year 1, PGY1), developed at the Pontificia Universidad Católica de Chile Medical School and published by Varas et al. [12].

Our advanced laparoscopic training program consisted of 16 sessions of increasing difficulty where trainees performed a complete hand-sewn jejuno-jejunostomy (JJO) in an ex vivo bench model using bovine small bowel [8, 12]. The JJO was deemed as an appropriate model given that laparoscopic intra-corporeal suturing and knot tying are considered some of the most technically demanding minimally invasive skills to acquire, constituting a requisite for surgeons to perform advanced laparoscopy [13]. In addition, the JJO incorporates various complex techniques, critical in advanced laparoscopic procedures, such as interrupted and continuous intra-corporeal sutures, or the use of an ultrasonic dissection device and endo-mechanical staplers.

After completing the advanced laparoscopic training program, PGY1 residents trained with simulation were assessed performing a stapled JJO in the OR as part of a LRYGB, assisted by a certified bariatric surgeon, responsible for the procedure and with the authority to interrupt the assessment based on pre-established criteria at any time (Table 1). The study was approved by the institutional ethics committee, and all patients were included after obtaining a written informed consent.

Two control groups were assessed performing the same stapled JJO in the OR; general surgeons (GS) graduated from traditional surgical residence programs without prior simulation training in their curricula; and certified laparoscopic bariatric surgeons experts (BS). Prior lifetime laparoscopic experience for all groups is given in Table 2. Of note, our institution 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 2014, more than 400 LRYGB surgeries were completed in our institution, ensuring the expertise of each surgeon recruited in this experimental protocol.

All procedures were video recorded and then evaluated by two blinded experts using a validated objective structured assessment of technical skill global rating scale (OSATS-GRS) and a procedure-specific rating scale (SRS), as given in Tables 3, 4 [8, 14]. Moreover, operative time and total path length (TPL) of both hands were measured with the Imperial College Surgical Assessment Device (ICSAD) [15]. Perioperative complications were also registered with a one-month period follow-up which included two outpatient control appointments with the primary surgeon within this period. Complications were categorized via the Clavien–Dindo complication index [16]. Trainees and GS were supervised in the OR by the same expert bariatric surgeon (C.B). Until the assessment was completed, there was no guidance for both trainees and general surgeons.

Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences version 21.0 (IBM SPSS software, IBM corporation, Armonk, New York) with nonparametric tests. Mann–Whitney and Kruskal–Wallis tests were used to compare each specific variable within each group, and the results were exposed as median and interquartile ranges (IQR). A value of $p < 0.05$ was considered statistically significant.

Sample size was calculated based on the results of the trainees transferring their surgical skills from simulation to a porcine model and when compared to general surgeons and experts [12]. The minimum number of trainees

Table 1 Pre-established criteria for the expert (BS) to take over surgery during the assessment

Frequent use of unnecessary force or damage caused by inappropriate use of instruments (if any trainee or GS has a GRS with less than 2 points in the item *Respect for tissue* [Table 3])
Repeatedly tentative and awkward moves with laparoscopic instruments (if any trainee or GS has a GRS with less than 2 points in the item *Instrument Handling* section [Table 3])
Frequently stops the procedure or needs for discussion on how to proceed to the next step. (if any trainee or GS has a GRS with less than 2 points in the item *Flow of Operation and Forward Planning* section [Table 3])
Deficient knowledge; requires instruction in most operative steps (if any trainee or GS has a GRS with less than 2 points in the item *Knowledge* [Table 3])
Maximum allowed time for performing the jejuno-jejunostomy of 40 min
Bowel mucosa or stapling line bleeding that requires additional hemostasis maneuvers

GS General surgeons without laboratory simulation training, *BS* bariatric surgeons, *GRS* global rating scale, *SRS* specific rating scale

Table 2 Number of prior (lifetime) basic and advanced laparoscopic procedures as primary or assistant surgeon

Laparoscopic procedure	Trainees		GS		BS
	Primary	Assistant	Primary	Assistant	Primary
Cholecystectomy	50 (17–78)	30 (15–43)	>200	>200	>300
Appendectomy	2 (0–3)	3 (0–6)	>100	>150	>300
Ventral/inguinal hernia repair	1 (0–2)	2 (1–5)	10 (3–14)	10 (2–18)	>50
Sleeve gastrectomy	0	12 (7–14)	14 (10–17)	30 (23–44)	>300
LRYGB	0	2 (1–3)	2 (0–4)	32 (26–37)	>300

Median (range)

GS General surgeons without laboratory simulation training, *BS* bariatric surgeons, *LRYGB* laparoscopic Roux-en-Y gastric bypass

Table 3 Generic global rating scale (GRS) of operative skill

Score	Respect for tissue	Time and motion	Instrument handling	Flow of operation and forward planning	Knowledge
1	Frequent use of unnecessary force. Damage caused by inappropriate use of instruments.	Many unnecessary moves.	Repeatedly makes tentative and awkward moves with instruments.	Frequently stops the procedure or requires discussing the next step.	Deficient knowledge and required instruction in most operative steps.
2					
3	Careful handling of tissue but occasionally causes inadvertent damage.	Efficient time/motion but performs some unnecessary moves.	Competent use of instruments although occasionally appeared stiff or awkward.	Demonstrated ability for forward planning with steady progression of the procedure.	Knew all important aspects of the operation.
4					
5	Consistently handles tissue appropriately with minimal damage.	Economy of movement and maximum efficiency.	Fluid moves with instruments and no awkwardness.	Obviously planned course of operation with effortless flow from one to the next.	Demonstrated familiarity with all aspects of the operation.

Modified version of the original global rating scale [8, 14]

transferring their skills to a real patient in the OR was estimated in 7. In order to compare differences in the performance in the OR, a minimum of 5 GS and 5 experts were required.

Results

A total of 10 PGY1 trained residents, 12 GS and 5 BS experts were assessed performing a JJO in the OR.

Table 4 Procedure-specific rating scale (SRS) for assessing a stapled jejuno-jejunostomy

Score	Laparoscopic stay suture placement	Enterotomy	Stapling	Enterotomy closure
1	Lack of dexterity in positioning needle, and driving through tissue. Does not attend to recognized knot techniques	Placed in a hazard manner. Poor relation between grasper and ultrasonic scalpel; excessively large or small	Unclear of how to use staple device. Drives staple jaws blindly into jejunum; closes jaws without both in bowel lumen	Poorly positioned stitch. Blindly placed continuous sutures with little regard to ensure enterotomy closure
2				
3	Needle held in appropriate position; appropriate technique of knot tying, although fumbles occasionally	Appropriate size of enterotomy, although performed with some hesitation.	Uses staple device with hesitation. Uses stay suture to place jaws, although lacks appreciation of the ideal angle for insertion	Adequate stitch position. Sutures placed at varying distances apart, with gathering of bowel edges
4				
5	Accurate needle positioning, placement and smooth knot tying technique	Appropriately sized and placed enterotomies, with no extra movements. Good relation of grasper and ultrasonic scalpel.	Places staple jaws with ease, and uses stay suture to draw bowel into jaws. Smooth, controlled fire with no widening of enterotomies.	Full thickness sutures placed at uniform distance apart

Modified version of the original specific rating scale [8]

All PGY1 trainees completed the entire JJO in the OR, without any takeovers by the BS. In the GS group, six (50 %) BS takeovers took place when meeting interruption criteria (Table 1).

Regarding OSATS-GRS (5–25 pts.), PGY1 trainees' median score was 19.5 pts. (18.8–23.5), GS median score was 12 pts. (9–13.8), and all BS scored the maximum of 25 pts. There were significant differences between all groups, $p < 0.001$ (Fig. 1A).

In the case of SRS (4–20 pts.), trainees' median score was 17 pts. (16–19), GS median score was 8.5 pts. (6.3–12), and all BS scored the maximum of 20 points. There were significant differences between all groups, $p < 0.001$ (Fig. 1B).

Operative time was significantly different between groups, with a median of 18.1 min (11.9–22) in the trainees group, 29.8 min (26.3–33.9) in the GS group, and 6 min (5.5–7.8) in the BS group (Fig. 2A).

When considering the economy of movements measured by ICSAD, trainees' median TPL covered by both hands was 123 m. (87–136), GS median TPL was 181 m. (141–236), and BS median was 50 m. (40–79). There were significant differences between all groups, $p < 0.001$ (Fig. 2B). Specific data and statistical comparison between each group are given in Table 5.

One patient in the trainees group was readmitted at postoperative day 10 (six days after having been discharged) for mechanical ileus with auto-resolution and

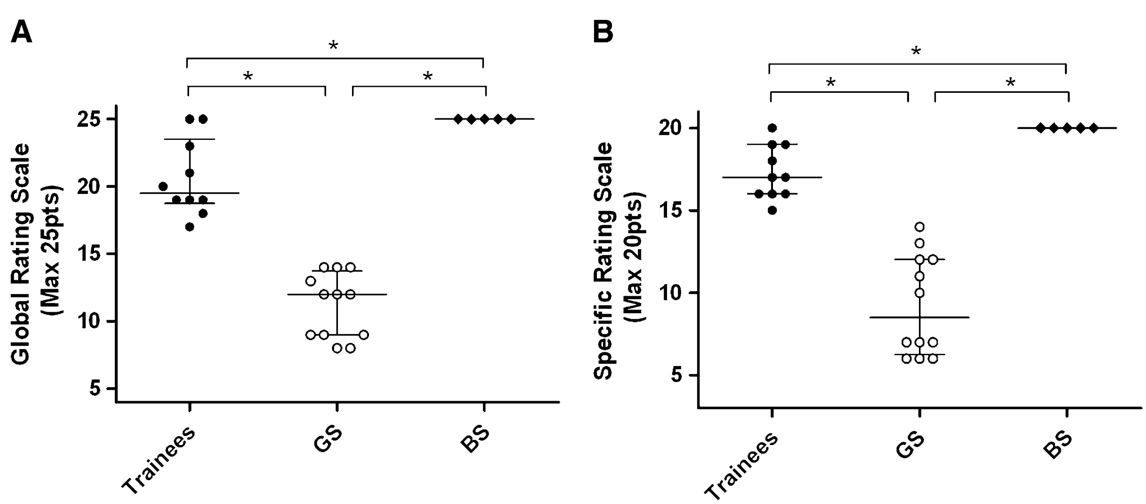

Fig. 1 **A** global and **B** specific rating OSATS scores obtained by trainees, general surgeon (GS) without laboratory simulation training and expert bariatric surgeons (BS), when performing a stapled jejuno-jejunostomy in the operating room

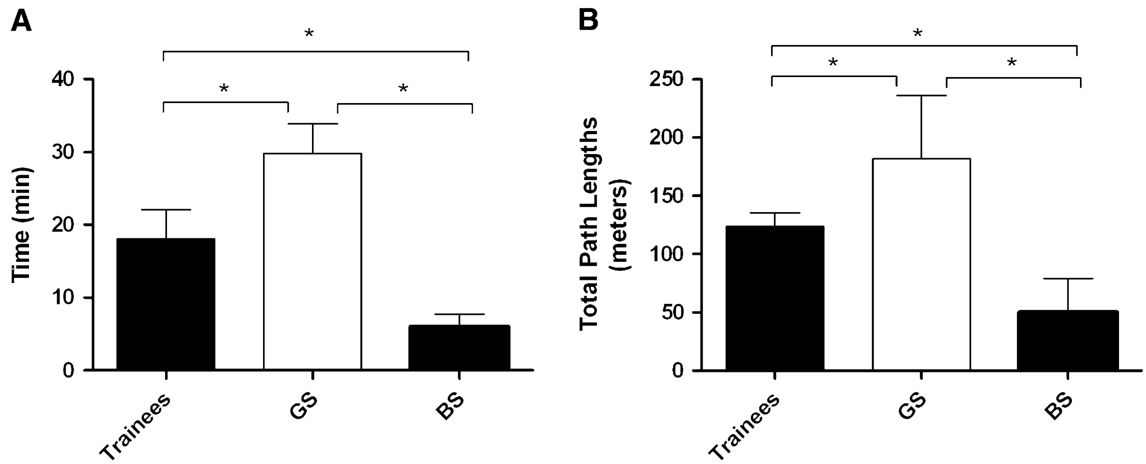

Fig. 2 Procedural time **A** and total distance or path length covered by both hands **B** obtained by junior residents (trainees), general surgeon (GS) without laboratory simulation training and expert bariatric surgeons (BS), to make a jejuno-jejunostomy of a LRYGP

discharge at postoperative day 13. There was no other morbidity–mortality registered for any other patient of this study at one-month follow-up.

Discussion

Currently, there is growing evidence supporting the systematic introduction of simulated training for laparoscopic surgery. Recently, Zendejas et al. [2] published a systematic review including 219 studies evaluating simulation-based training versus traditional programs or no specific intervention. The authors showed better results in the simulation groups in terms of knowledge, behavior and skills acquisition after training [2]. Furthermore, they found that box-trainer-type simulators are associated with moderately greater outcomes than virtual reality (VR) simulators regarding learner satisfaction and task time, independently to the addition or not of computer-enhanced haptic feedback [2]. The present study demonstrates that first year residents with laboratory bench model simulation training may technically perform advanced laparoscopic procedures in the OR.

Despite multiple publications, there is currently lack of guidelines for the implementation of standardized simulated training programs for advanced laparoscopy. Most reports include basic suture skills, and only few involve more complex procedures such as Nissen fundoplication [17], JJO [18], sleeve gastrectomy [19], etc. [11, 17, 20–22]. However, most of proficiency assessment after training is performed in the skills laboratory, and very few have reported evaluation of skills transfer to a more complex scenario as the OR. The curriculum described in this study is unique in comparison with the small number of well-structured curricula described in previous literature for advanced laparoscopic skills [11] as it assessed trainees performing a complete bowel anastomosis in the OR and compared them to surgeons graduated from traditional programs without simulation training (Table 2).

The present [12] advanced laparoscopic training program has several educational advantages. Before initiating our program, all students are required to complete a basic laparoscopic curriculum that includes FLS course and VR training, in order to acquire essential skills and thus optimize training sessions. Moreover, our training program contains multiple evidence-based educational strategies in

Table 5 Results of laparoscopic JJO performance in the operative room (range)

Category	Trainees[a]	GS[b]	BS[c]	[abc]p value[+]	[ab]p value[++]	[bc]p value[++]	[ac]p value[++]
GRS, median (range 5–25)	19.5 (17–25)	12 (8–14)	25	<0.001	<0.001	<0.001	0.013
SRS, median (range 4–20)	17 (15–20)	8.5 (6–14)	20	<0.001	<0.001	<0.001	0.003
TPL (meters), median	123 (65–206)	181 (127–250)	50 (35–80)	<0.001	0.001	<0.001	0.001
Operative time (min), median	18.1 (9.7–25)	29.8 min (17–42)	6 (5–9.5)	<0.001	0.002	<0.001	0.008

[+] p values obtained with Kruskal–Wallis test; [++] p values obtained with Mann–Whitney test

GS General surgeons, *BS* bariatric surgeons, *GRS* global rating scale, *SRS* specific rating scale, *TPL* both hands total path length order to optimize and validate learning, such as: an initial assessment with a previous video master class; blinded initial and final assessments, incorporation of validated OSATS [23]; motion tracking devices like ICSAD [15]; a modified validated bench model [8], complete videos with meticulous details on how to complete each session; and standardized training sessions with effective feedback by a surgical instructor expert [24].

This report corresponds to the final phase in our institutional study, aimed to evaluate the effectiveness of our laparoscopic simulated training program for surgical residents. According to Kirkpatrick's four-level learning evaluation model [25, 26], effectiveness of our simulated training program was established in all measurable levels.

Level 1 (*Reaction*) and level 2 (*Learning*) were accomplished during the first phase: laboratory training and live porcine model assessment [12].

With respect to level 3 (*transfer*), as stated previously, in surgical simulation the greatest challenge is to demonstrate the efficiency of a simulation program when transferred to the real scenario, in this case the OR [27]. In this study, we demonstrate the transfer to the OR of advanced laparoscopic skills acquired through a simulated training program in beginner surgical residents, performing a complex procedure such as laparoscopic JJO.

Finally, regarding level 4 of Kirkpatrick model (*organizational value*), as from this pilot study in our institution, there has been a continuous growth in simulation programs in response to its good results, offering residents and trainees the opportunity to learn under an objective structured training program. This includes a complete infrastructure installed right next to the main clinical hospital, exclusive personal and available staff members, in addition to a dedicated surgical simulation research fellow.

This study demonstrates positive findings; however, there are some limitations that should be discussed. In the first place, there is a low number of participants in each group assessed in the OR, mainly due to specific time-dependent training pre-required (basic and advanced simulated training in all PGY1 residents) and concerns on patient's safety (in the case of GS group). Nonetheless, this study was carried out in compliance with the minimum sample size calculated and thus statistically significant differences in results between each group were obtained for all categories. Secondly, the results achieved with simulated training were evaluated immediately after completing the program and probably do not reflect a real and sustained acquisition of skills after training. As other authors have proposed recently [27], assessment of proficiency at mid- and long term is required in order to establish retention of learned skills over time. While in this experience first year residents trained with simulation were compared in a single assessment to GS, efforts should be made in a future to obtain and compare learning curves between these groups in the OR. Thus, knowing both learning curves would allow us to determine how much training time should a trainee spend in the laboratory in order to become proficient in the OR (cumulative transfer effectiveness ratio) [28].

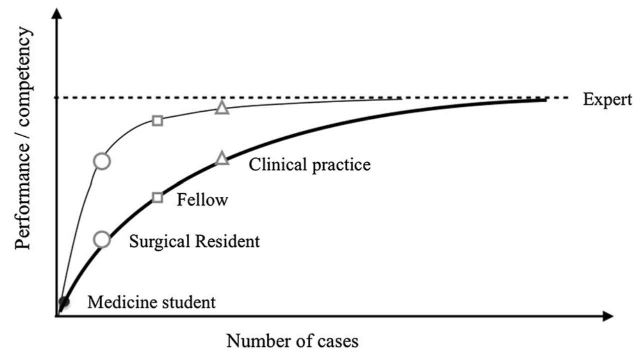

Fig. 3 Difference between the course of improvement when adding simulation (*thin line*) to a traditional competency-based learning curve (*bold line*) [30]

Our results indicate that first year residents with simulation training may be significantly better not only in how they operate (GRS and SRS scores), but also in terms of speed. Figure 2A and Table 5 show that trainees take nearly half the time in performing the same advanced laparoscopic procedure when compared to GS. Probably if residents and fellows were always trained with simulation, more daily procedures could be performed at our institution. Investing in this type of simulation training could end up lowering institutional costs associated with resident education as stipulated by Harrington et al. [29]. However, cost analysis studies should be conducted to assess true institutional impact of executing simulation training programs.

Figure 3 plots our results on Ericsson's surgeon learning curve [30], proposing that simulation training shortens novice's learning process in becoming experts, adding a clear advantage over traditional programs without simulation. Figure 3 also suggests that surgical simulation may benefit a surgeon at any stage of their clinical formation and practice, since student or rookie resident, when specializing in a clinical fellow or even if the surgeon has an ongoing daily clinical practice. Surgical simulation should involve different training programs with progressive difficulty according to the stages of formation of a surgeon.

Conclusion

The present study demonstrated transfer of advanced laparoscopic skills acquired through a simulated training program in novice surgical residents to the OR. We propose an incorporation of simulated advanced laparoscopic programs as an education complement in surgical training curricula due to its significant impact on quality of training, OR efficiency and potential to benefit patient safety.

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Compliance with ethical standards

Disclosures Drs. Camilo Boza, Felipe León, Erwin Buckel, Arnoldo Riquelme, Fernando Crovari, Jorge Martínez, Teodor Grantcharov, Nicolás Jarufe and Julián Varas have no conflicts of interest or financial ties to disclose.

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