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ORIGINAL ARTICLE

Effect of three training programs on surgical performance in single-port laparoscopic surgery

Efecto de tres programas de entrenamiento sobre el desempeño en cirugía laparoscópica por puerto único

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Abstract

Objective: *The aim of this study was to evaluate the effect of three training methodologies on the acquisition of psychomotor skills for laparoendoscopic single-site surgery (LESS), using straight and articulating instruments.* **Methods:** *A prospective study was conducted with subjects randomly divided into three groups, who performed a specific training for 12 days using three laparoscopic tasks in a laparoscopic simulator. Group-A trained in conventional laparoscopy setting using straight instruments and in LESS setting using both straight and articulating instruments. Group-B trained in LESS setting using straight and articulating instruments, whereas Group-C trained in LESS setting using articulating instruments. Participants' performance was recorded with a video-tracking system and evaluated with 12 motion analysis parameters (MAPs).* **Results:** *All groups obtained significant differences in their performance in most of the MAPs. Group-C showed an improvement in nine MAPs, with a high level of technical competence. Group-A presented a marked improvement in bimanual dexterity skills.* **Conclusions:** *Training in LESS surgery using articulating laparoscopic instruments improves the quality of skills and allows smoother learning curves.*

Keywords: *Laparoscopy. Single-incision. Articulating instruments. Objective assessment. Performance.*

Resumen

Objetivo: *Evaluar el efecto de tres métodos de entrenamiento en la adquisición de habilidades psicomotrices para la cirugía laparoendoscópica por puerto único (LESS, laparoendoscopic single-site surgery) utilizando instrumental recto y articulado.* **Método:** *Se realizó un estudio prospectivo con sujetos divididos aleatoriamente en tres grupos, quienes realizaron un entrenamiento específico durante 12 días utilizando tres tareas laparoscópicas en un simulador laparoscópico. El grupo A entrenó en el entorno laparoscópico convencional con instrumentos rectos, y en el entorno LESS con instrumentos rectos y articulados. El grupo B entrenó en el entorno LESS con instrumentos rectos y articulados. El Grupo C entrenó en el entorno LESS con instrumentos articulados. El desempeño de los participantes se registró con un sistema de seguimiento en video y fue evaluado con 12 parámetros de análisis de movimiento (MAP, motion analysis parameters).* **Resultados:** *Todos los grupos obtuvieron*

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diferencias significativas en su desempeño para la mayoría de los MAP. El grupo C mostró una mejora en nueve MAP, con un alto nivel de competencia técnica. El grupo A mostró una marcada mejora en la habilidad de destreza bimanual. **Conclusiones:** *El entrenamiento en cirugía LESS con instrumentos articulados mejora la calidad de las habilidades adquiridas y permite curvas de aprendizaje más suaves.*

Palabras clave: *Laparoscopia. Incisión única. Instrumentos articulados. Evaluación objetiva. Desempeño.*

Introduction

In recent years, one of the main targets in the field of surgery has been the reduction of iatrogenic trauma caused during surgical procedures. This objective has led to the innovation and invention of new techniques, which are included in what is called minimally invasive surgery (MIS)[1]. Within this surgical field, laparoscopic surgery has been the choice of surgeons for many years due to the miniaturization of large incisions, resulting in a reduction of tissue trauma, fewer postoperative complications, and better cosmetic results[2]. However, the need arises to implement a structured educational program for these surgical techniques, where the necessary technical skills and cognitive knowledge can be acquired to perform laparoscopic surgery in a safe and reliable manner.

In the education context, the American Society of Gastrointestinal and Endoscopic Surgeons developed the Fundamentals of Laparoscopic Surgery (FLS) educational program, in which surgeons can acquire and refine the minimally invasive technique through its basic laparoscopic training modules[3,4]. Nevertheless, the European Association of Endoscopic Surgery (EAES) has recently analyzed the current needs of skills training in MIS, detecting a significant educational gap, in which trainees were not undertaking enough training activities to feel confident in their skills[5]. Recently, new surgical techniques have been developed to further reduce the invasiveness generated by laparoscopic surgery, such as the case of laparoendoscopic single-site (LESS) surgery, where a single incision is made in the umbilicus through which a multi-access port is placed and can be used as the main access to the patient's abdominal cavity in its four quadrants[6]. This LESS technique, similar to conventional laparoscopic surgery (CLS), has demonstrated safety and efficacy, so it could therefore be considered a good surgical treatment option. However, it shows some disadvantages with respect to CLS such as a long learning curve, greater complexity, execution time, and higher cost in certain procedures, and poor ergonomics for the surgeon[7,8].

Some of the aforementioned limitations when performing surgical procedures by means of the LESS technique include the loss of triangulation with the reduction of the field of vision, inverted manipulation of the instruments due to the crossing of tools, less intuitive and imprecise movements requiring greater concentration, visual interference between the surgical instruments and the endoscopic camera due to the reduced working space, and the use of instruments with unfamiliar characteristics, making it difficult to maintain surgical safety for the patient and a significant technical challenger[9,10]. On the other hand, the use of articulating instruments can help to minimize these problems because they expand the work area and their steerable tips allow to perform triangulation more easily, making this kind of instrument the recommended choice when performing LESS procedures.

Regarding LESS learning, the EAES has recently published a consensus on LESS surgery, which gathers all the available evidence on this topic and outlines the advantages and disadvantages of LESS, addressing the general aspects of this surgical procedure as well as organ-specific issues[11]. There is a need to redesign specific training programs for the acquisition of skills in LESS, where surgeons can be prepared for the drawbacks related to this surgical technique. Several studies have been published regarding the learning process of LESS surgery. Most of them conclude that specific training in LESS is necessary and therefore a specific educational program for LESS surgery is needed. Therefore, training oriented to the use of the different specific access devices for LESS surgery[12], as well as the different types of laparoscopic instruments, such as straight, curved, and articulating, can considerably improve the quality of the surgeon's performance in this surgical technique[13].

The aim of this study is to evaluate the impact of three training settings on the acquisition of surgical skills for LESS surgery, using straight and articulating laparoscopic instruments. The study was conducted using a laparoscopic box trainer, adapted both for conventional and single-port laparoscopy configurations,

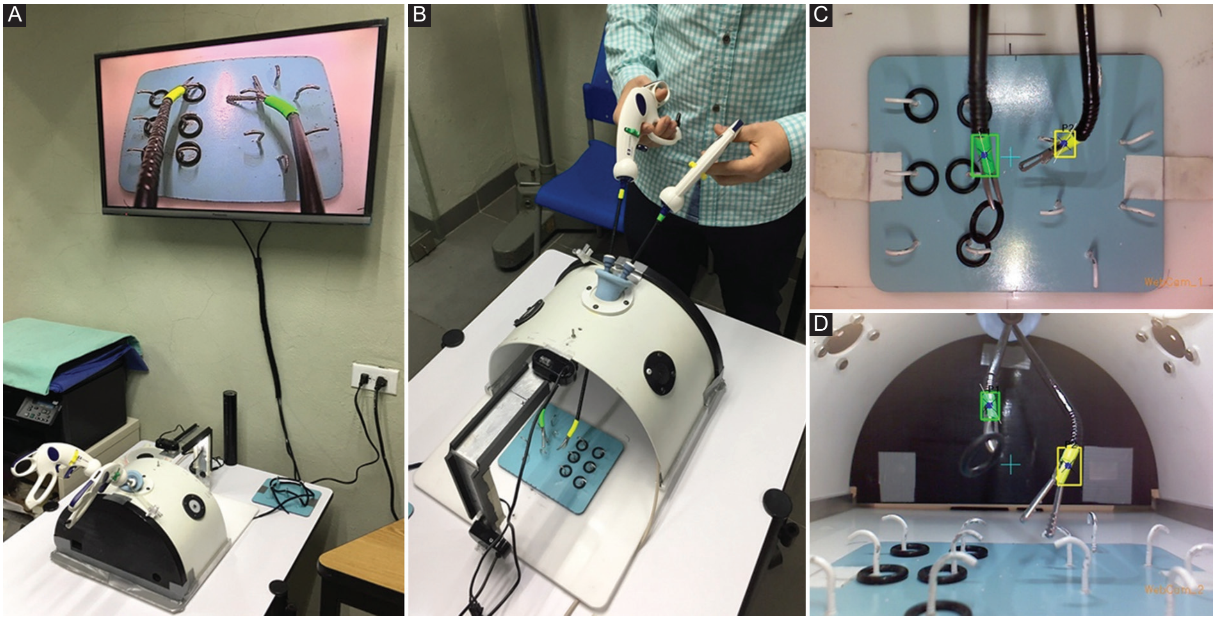

Figure 1. A: *experimental setup of the laparoscopic box simulator.* **B:** *adaptation allowing the use of the SILS™ access port. Motion tracking of the articulating laparoscopic instruments with the orthogonal video-based tracking system of the simulator.* **C:** *top.* **D:** *front views of the color markers in the instruments.*

with an integrated video tracking system. The performance of the participants was analyzed at the beginning and the end of the study using 12 motion analysis parameters (MAPs). With these training programs, we studied if acquiring experience in CLS with straight instruments before jumping to LESS with articulating instruments has an effect on the final proficiency achieved for LESS surgery. We hypothesized that dedicated training in a single-port surgery setting with articulating laparoscopic instruments would improve the acquisition and quality of skills, as well as the surgeon's performance metrics in basic laparoscopic tasks.

Materials and methods

Participants

A total of 30 final-year medical students from the Faculty of Medicine of the National Autonomous University of Mexico (UNAM) were invited to participate in the study. Thirty participants (14 female and 16 male) all right-handed and with no previous experience in minimally invasive surgical techniques, voluntarily enrolled in this study. At the time of the invitation, written informed consents were obtained from all individual participants included in this study. This research was approved by the Ethics, Biosafety, and Research Committee of the Faculty of Medicine at UNAM, under the number code 015/2016.

Equipment

For this study, a laparoscopic box trainer with a built-in orthogonal camera system inside was used, which allows the tracking and motion analysis of the surgical instruments (Fig. 1A). This orthogonal camera system captures the three-dimensional (3D) movements of the laparoscopic instruments within the workspace by means of color markers[14,15] (Figs. 1 C and D). In the study, this box trainer was adapted for training in two configurations: (1) CLS and (2) LESS surgery (Fig. 1B). As an intracorporeal camera, with 0-degree optics, a 750TVL resolution color mini-camera installed below the semicylindrical cavity of the box trainer was used. To simulate the single-port laparoscopic surgery configuration, a SILS™ access port (Medtronic, Minneapolis, MN, USA) was inserted in the center of the semicylindrical cavity, through which the surgical instruments were inserted inside the simulator. In the study, a set of 5-mm standard straight and articulating laparoscopic instruments, which include dissectors, forceps, and scissors (Medtronic, Minneapolis, MN, USA), was used to perform the training tasks with the laparoscopic box trainer in both settings. The straight laparoscopic instruments used include a pair of graspers with atraumatic tips, a pair of Maryland dissection forceps, and scissors, which allow 4° of freedom (DoFs) of movement around the incision point, whereas the articulating laparoscopic

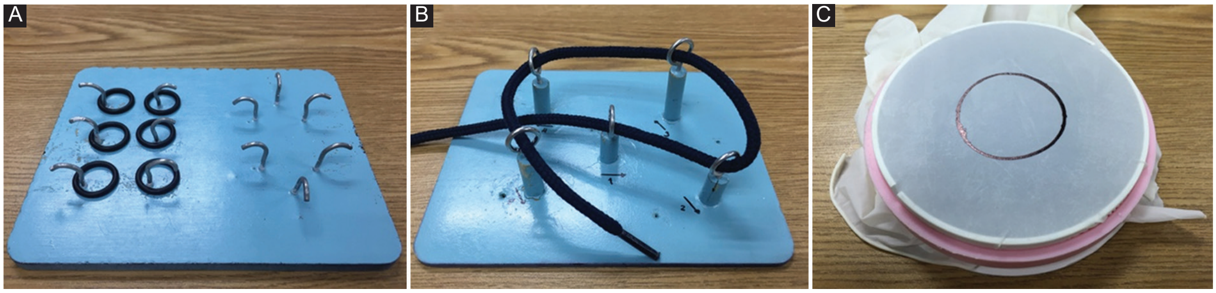

Figure 2. *Laparoscopic training tasks.* **A:** *peg transfer.* **B:** *labyrinth.* **C:** *circular cutting.*

instruments used include a pair of graspers with atraumatic tips, a pair of Maryland dissection forceps and scissors, which allow two additional DoFs of movement at their tips and they are deflectable up to 80° with respect to the incision point.

Tasks

Participants performed three laparoscopic tasks in this study, based on the FLS program and the MISTELS protocol[16,17], for 12 consecutive days. The tasks were performed in the following order:

- Peg transfer (PT): This task consisted of lifting six rubber rings (one by one) from one set of curved posts with the left laparoscopic grasper, transferring them to the right laparoscopic grasper, and placing them on the second set of curved posts (Fig. 2A)
- Labyrinth (L): This task entailed passing a thread through a circuit of five posts with rings placed at different positions and heights. The thread was inserted into each of the rings according to the assigned numbering and direction using both graspers (Fig. 2B)
- Circular cutting: This task consisted of cutting a 4.5-cm circle line on a latex glove stretched on a platform. Participants had to cut along the marked line as precisely as possible using the scissors while applying traction to the latex using the grasper. The task ended when the circle was completely cut out and separated from the glove (Fig. 2C).

Study design

The participants were randomly divided into three groups using the block randomization technique, Group-A, Group-B, and Group-C, of 10 participants each. Figure 3 shows a schematic illustrating the experimental study design. Group-A performed the three training tasks for 12 consecutive days in three phases. In the first phase, the participants trained in CLS setup using straight laparoscopic instruments for 4 days. In the second phase, they switched to LESS setup and trained for 4 days crossing the straight laparoscopic instruments. In the third phase, they continued in LESS setup and trained for the remaining 4 days crossing the articulating laparoscopic instruments. Group-B performed the three training tasks for 12 consecutive days in two phases. In the first phase, the participants trained in LESS setup for 6 days crossing the straight laparoscopic instruments. In the second phase, they continued in LESS setup and trained to cross the articulating laparoscopic instruments for the remaining 6 days. Finally, Group-C performed the three tasks in LESS setup and trained to cross the articulating laparoscopic instruments for 12 consecutive days. Before starting their specific training, all participants received instructions on how to perform and complete each of the three training tasks, as well as technical information about the use and degrees of freedom of straight and articulating laparoscopic instruments. The laparoscopic simulator was placed at a suitable height and position to comfortably perform all three tasks. To ensure the same conditions for all participants in the study, the position of the tasks inside the box trainer, the configuration of the input ports for conventional and single-port laparoscopy, and the position of the camera were standardized for each of them. During each day of the training process, all participants performed a minimum of three repetitions for each task, and no maximum limit of daily repetitions was imposed on them during the study.

Assessment of the psychomotor skills

In this study, the psychomotor MIS skills of all participants were evaluated before and after their 12-day assigned training program, using the box trainer in

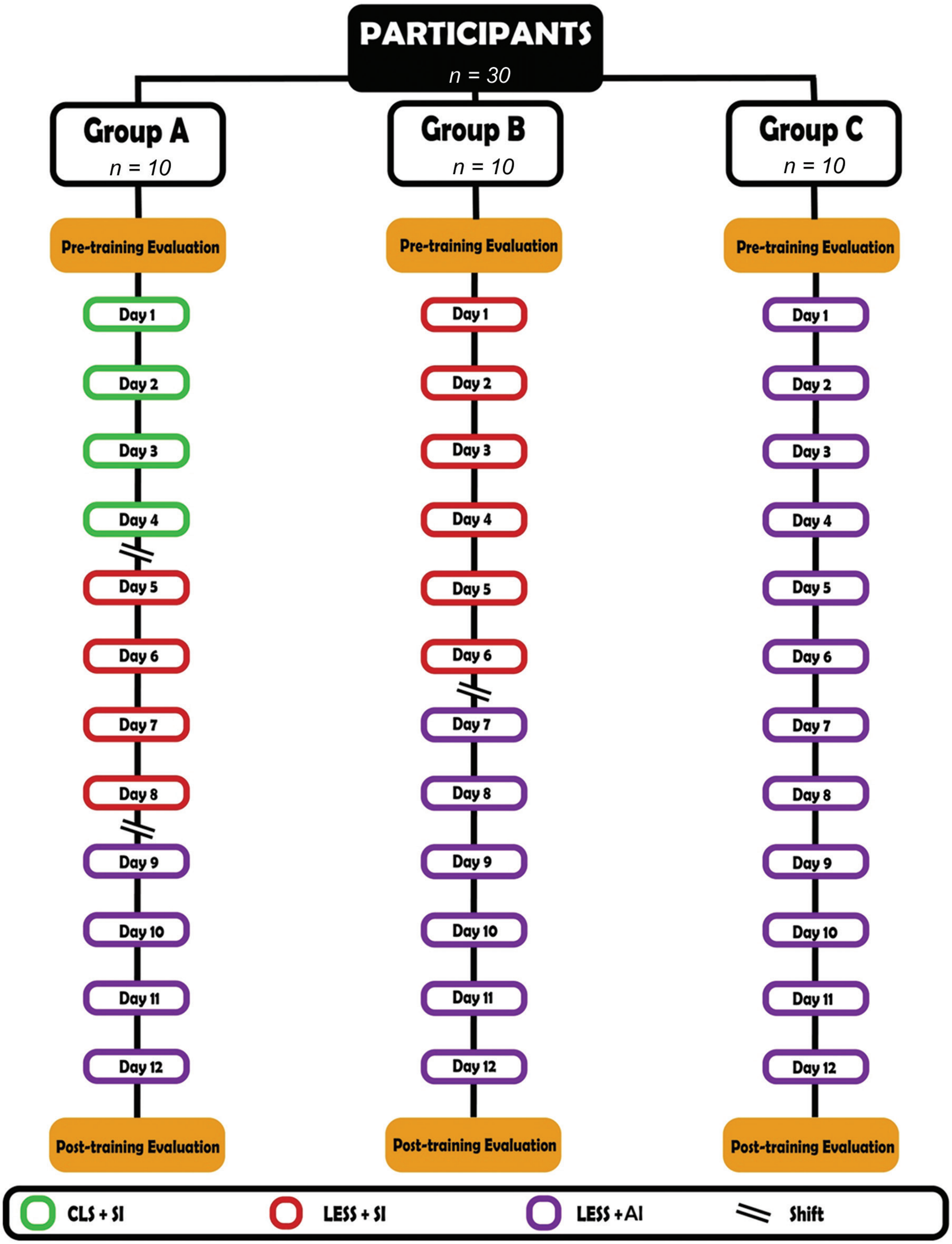

Figure 3. *Study protocol design. CLS+SI: conventional laparoscopic surgery configuration with straight instruments. LESS+SI: laparoendoscopic single-site configuration with straight instruments. LESS+AI: laparoendoscopic single-site configuration with articulating instruments.*

LESS surgery setting, (i.e., crossing the articulating laparoscopic instruments and performing the three laparoscopic tasks). The recorded motion data of the articulating laparoscopic instruments were analyzed using 12 MAPs (Table 1)[18-20]. These MAPs were calculated from the position $[x(t), y(t), z(t)]_{t=0}^{T}$ of the

Table 1. Selection of MAPs for assessing the LESS performance

Metrics	Definition	Equation
Time (T)	The total time required to perform the task. (seg)	T
Bimanual dexterity (BD)	The correlation between the velocities of both instruments during the task. (-)	$\frac{\sum_{n=1}^{N}\left(v_{left}(n)-\bar{v}_{left}\right)\left(v_{right}(n)-\bar{v}_{rigth}\right)}{\sqrt{\sum_{n=1}^{N}\left(v_{left}(n)-\bar{v}_{left}\right)^2\sum_{n=1}^{N}\left(v_{right}(n)-\bar{v}_{rigth}\right)^2}}$
Path length (PL)	Total path followed by the tip of the instrument while performing the task. (m)	$\int_{t=0}^{T}\sqrt{\left(\frac{dx}{dt}\right)^2+\left(\frac{dy}{dt}\right)^2+\left(\frac{dz}{dt}\right)^2}\,dt$
Depth perception (DP)	Total distance traveled by the instrument along its axis. (m)	$\int_{t=0}^{T}\sqrt{\left(\frac{dy}{dt}\right)^2+\left(\frac{dz}{dt}\right)^2}\,dt$
Motion smoothness (MS)	Abrupt changes in acceleration result in jerky movements of the instrument. (m/s^3)	$\sqrt{\frac{T^5}{2\cdot PL^2}\int_{t=0}^{T}\left(\left(\frac{d^3x}{dt^3}\right)^2+\left(\frac{d^3y}{dt^3}\right)^2+\left(\frac{d^3z}{dt^3}\right)^2\right)^2 dt}$
Average velocity (V)	Rate of change of the position of the instrument. (mm/s)	$\frac{1}{T}\int_{t=0}^{T}\sqrt{\left(\frac{dx}{dt}\right)^2+\left(\frac{dy}{dt}\right)^2+\left(\frac{dz}{dt}\right)^2}\,dt$
Average acceleration (A)	Rate of change of the velocity of the instrument. (mm/s^2)	$\frac{1}{T}\int_{t=0}^{T}\sqrt{\left(\frac{d^2x}{dt^2}\right)^2+\left(\frac{d^2y}{dt^2}\right)^2+\left(\frac{d^2z}{dt^2}\right)^2}\,dt$
Idle time (IT)	Percentage of time where the instrument was considered still. (%)	$\frac{\lvert\Im\rvert}{T}:\Im=\frac{1}{T}\int_{t=0}^{T}\sqrt{\left(\frac{dx}{dt}\right)^2+\left(\frac{dy}{dt}\right)^2+\left(\frac{dz}{dt}\right)^2}\,dt\le 5$
Economy of area (EOA)	Relation between the maximum surface area covered by the instrument and the total path. (-)	$\frac{\sqrt{\left[Max(x)-Min(x)\right].[Max(y)-Min(y)]}}{PL}$
		$\frac{\sum_{t=0}^{T}\lvert x_i\rvert^2+\sum_{t=0}^{T}\lvert y_i\rvert^2+\sum_{t=0}^{T}\lvert z_i\rvert^2}{\left[Max(x)-Min(x)\right]\cdot\left[Max(y)-Min(y)\right]\cdot\left[Max(z)-Min(z)\right]}$
Economy of volume (EOV)	Relation between the maximum volume covered by the instrument and the total path. (-)	$\frac{\sqrt[3]{\left[Max(x)-Min(x)\right]\cdot\left[Max(y)-Min(y)\right]\cdot[Max(z)-Min(z)]}}{PL}$
Energy of area (EA)	Energy inverted by the instrument over the surface area covered. (J/cm^2)	$\frac{\sum_{t=0}^{T}\lvert x_i\rvert^2+\sum_{t=0}^{T}\lvert y_i\rvert^2}{\left[Max(x)-Min(x)\right]\cdot[Max(y)-Min(y)]}$
Energy of volume (EV)	Energy is inverted by the instrument over the volume covered. (J/cm^3)	$\frac{\sum_{t=0}^{T}\lvert x_i\rvert^2+\sum_{t=0}^{T}\lvert y_i\rvert^2+\sum_{t=0}^{T}\lvert z_i\rvert^2}{\left[Max(x)-Min(x)\right]\cdot\left[Max(y)-Min(y)\right]\cdot\left[Max(z)-Min(z)\right]}$

surgical instruments recorded by the video-based tracking system installed in the simulator and computed in MATLAB Release 2020b (MathWorks, Natick, MA).

Statistical analysis

The MAPs' results were statistically analyzed using SPSS version 20.0 software for Windows (SPSS Inc., Chicago, IL, USA). Non-parametric tests were performed to analyze the data derived from the MAPs. To verify that the three groups confirmed the same level of psychomotor MIS skills at the beginning of the study, the Kruskal–Wallis and Mann–Whitney tests were used to find statistically significant differences in the initial performance between the three groups and for each pair of groups, respectively. Likewise, the Mann–Whitney test was performed to identify statistically significant differences between the initial and final performance of each of the three groups. In addition, the Kruskal–Wallis test was used to compare the performance between the three groups, and, where statistically significant differences were found, the Mann–Whitney test was used for pairwise comparisons of groups. In all cases, a value of $p < 0.05$ was considered statistically significant.

Results

A total of 27 participants completed the training during the study. Three participants, two in Group-A and one in Group-C, were unable to complete their assigned training due to conflicts with their schedules. The performance results of the 27 participants before and after specific training are presented in table 2. All MAPs, apart from time and bimanual dexterity, are presented separately for both the right and left hand.

Statistical analysis of the initial performance of the three groups did not show statistically significant differences in MAPs, confirming that they had a similar level of psychomotor MIS skills for the three laparoscopic tasks before starting their specific training in this study.

In general, all groups obtained statistically significant differences in their pre- and post-training in most of the MAPs analyzed for the three laparoscopic tasks. Group-B was the one that showed statistically significant improvement in performance for a higher number of MAPs after their assigned training, except for the PT task, in which it presented the same number of MAPs as Group-C. Furthermore, Group-B showed improvements in all their MAPs, except for bimanual dexterity, for the PT and L tasks. In addition, this group was the only one to achieve an improvement in idle time and energy invested in the working area and volume for both hands in all tasks. In the cutting task, none of the three groups showed significant changes in velocity and acceleration during the use of the articulated laparoscopic instruments. On the other hand, Group-A significantly improved bimanual dexterity in all three laparoscopic tasks. However, this group tended to hold both laparoscopic instruments longer in an idle state.

Concerning the PT task, after training, Group-C reduced the distance traveled by the instrument on the dominant hand and improved depth perception, the economy of the area, and energy invested in the volume of work by the non-dominant hand instrument with respect to Group-B. Group-C significantly reduced the energy invested in the working area by the instrument of the non-dominant hand with respect to the rest of the study groups. Regarding the L task, Group-C improved the motion smoothness in the use of the instrument handled by the dominant hand and increased the speed of movements and their acceleration with respect to Group-A. Similarly, for the instrument on the non-dominant hand, depth perception was improved. In the case of the cutting task, Group-C improved its bimanual dexterity. However, no significant differences were shown between study groups for the parameters evaluated for both the right and left hands.

Discussion

LESS surgery is considered an evolution from CLS due to the cosmetic advantages it presents[21]. However, this surgical approach involves important new technical challenges for the surgeon, different from those in CLS. The purpose of this study was to compare the acquisition of surgical skills for LESS surgery through three training modalities using straight and articulating instruments. We also evaluated trainees' performance and skill transfer in this single-access surgical technique using MAPs on a laparoscopic box trainer simulator with a video-based motion tracking system.

In the study, all three training groups showed improvement in their surgical performance using the LESS setting (Table 2). In particular, Group-C obtained the best results in their LESS performance after the 12-day training, reflecting an overall improvement in MAPs, with respect to the other groups for all three

Table 2. Results of the assessment Pre- versus Post-training in LESS configuration for the three laparoscopic tasks. For each MAPs, p-values are given

MAPs	Peg transfer			Labyrinth			Circular cutting		
	A	B	C	A	B	C	A	B	C
Time (s)	**0.002**	**0.000**	**0.000**	**0.001**	**0.000**	**0.000**	**0.001**	**0.000**	**0.000**
Bimanual Dexterity (-)	**0.002**	0.218	0.051	**0.015**	0.853	0.258	**0.021**	0.579	**0.006**
Right hand									
Path Length (cm)	**0.007**	**0.000**	**0.008**†	**0.007**	**0.005**	**0.003**	**0.003**	**0.000**	**0.001**
Depth Perception (cm)	**0.007**	**0.000**	**0.006**	**0.015**	**0.007**	**0.001**	**0.002**	**0.000**	**0.002**
Motion Smoothness (cm/s^3)	**0.002**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**‡	**0.003**	**0.000**	**0.000**
Velocity (mm/s)	**0.005**	**0.000**	**0.000**	0.083	**0.000**	**0.011**‡	0.798	0.218	0.050
Acceleration (mm/s^2)	**0.007**	**0.000**	**0.000**	0.130	**0.000**	**0.040**‡	0.328	0.247	0.063
Idle time (%)	**0.021**	**0.000**	**0.002**	0.234	**0.001**	0.051	0.328	**0.035**	0.113
EOA (-)	**0.005**	**0.000**	**0.003**	**0.010**	**0.002**	**0.006**	**0.003**	**0.000**	**0.002**
EOV (-)	**0.005**	**0.000**	**0.004**†	**0.005**	**0.002**	**0.002**	**0.003**	**0.000**	**0.002**
Energy in the Area (J/cm^2)	**0.002**	**0.001**	**0.000**	**0.021**	**0.019**	**0.031**	0.130	**0.011**	0.113
Energy in the Volume (J/cm^3)	**0.002**	**0.019**	**0.001**	0.105	**0.000**	0.222	0.195	**0.035**	**0.063**
Left hand									
Path Length (cm)	**0.003**	**0.000**	**0.004**	**0.001**	**0.001**	**0.008**	**0.003**	**0.000**	**0.000**
Depth Perception (cm)	**0.003**	**0.001**	**0.004**†	**0.003**	**0.001**	**0.014**‡	**0.007**	**0.001**	**0.000**
Motion Smoothness (cm/s^3)	**0.002**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**	**0.001**
Velocity (mm/s)	**0.049**	**0.000**	**0.000**‡	**0.007**	**0.001**	**0.008**	0.442	0.912	0.436
Acceleration (mm/s^2)	**0.028**	**0.000**	**0.000**	0.065	**0.001**	**0.024**	0.382	0.971	0.340
Idle time (%)	0.105	**0.003**	**0.000**	0.130	**0.007**	**0.004**	0.234	0.579	0.258
EOA (-)	**0.002**	**0.001**	**0.001**†	**0.002**	**0.000**	**0.011**	**0.007**	**0.000**	**0.000**
EOV (-)	**0.002**	**0.000**	**0.000**†	**0.001**	**0.001**	**0.014**	**0.001**	**0.000**	**0.000**
Energy in the Area (J/cm^2)	**0.038**	**0.000**	**0.002**‡†	**0.005**	**0.003**	0.063	0.574	**0.001**	0.931
Energy in the Volume (J/cm^3)	0.105	**0.000**	**0.004**†	**0.007**	**0.004**	0.063	0.798	**0.029**	0.730

Mann–Whitney *U*-test, significant differences at the $p < 0.05$ level are indicated in bold. Significant differences in final performance between groups B and C are marked as †, and between groups A and C are marked as ‡.

training tasks. These results confirm our initial hypothesis that this training focused solely on the single-port surgery approach with articulating instruments improves the acquisition and quality of LESS skills, achieving a decrease in the scores of all the MAPs analyzed. We believe that this is because the participants of this group quickly learned to master the LESS technique, as well as the coordination of movement and spatial orientation of the articulated instruments, (which makes this surgical technique more complex), and to correct the mistakes they made as the training progressed.

Group-A presented improvement in the ability to control both instruments in a coordinated fashion, being the only group to achieve statistically significant differences in the bimanual dexterity parameter for the three laparoscopic tasks performed. This interesting result could be due to this group had the opportunity to train with all instrument configurations (straight and articulating) and with all types of surgical approaches (standard ports and single-port), which most likely contributed greatly to improving the spatial orientation and movement coordination in the use of the surgical instruments with both hands. This finding suggests that Group-A learns quickly to master the skills and competencies required for the surgical modality in shift, such as conventional laparoscopy or single-port surgery. However, further studies are needed to explain this hypothesis. Group-B showed improvement in their performance, obtaining statistically significant differences in most of the MAPs analyzed for the three laparoscopic tasks. However, this group did not show improvement in the coordinated control of both instruments, as measured by the bimanual dexterity parameter. We believe that these results are due to participants having started their assigned training with straight instruments and a single-port approach, which greatly limited the spatial orientation and freedom of maneuvering in the handling of the instruments at the beginning of their training, which they had to correct later with the change to articulating instruments.

Comparing the final proficiency between the three groups, we found a few significant differences (Table 2). In the transfer task, 6 MAPs presented significant differences between groups B and C, between groups A and C only two MAPs presented significant differences, and no significant differences were found between groups A and B. For the L task, four MAPs presented significant differences between groups A and C, meanwhile, no differences were found between groups B and C or A and B. Finally, in the cutting task, no significant differences were found in the final performance between any of the three groups. These results indicate us that the three groups' final proficiency significantly increased compared to their initial proficiency, as demonstrated by the improvement of most MAPs between the individual measures pre- and post-training, showing the effectiveness of the training schedules.

Overall, results showed that switching from straight instruments to articulating instruments had little influence on participants' skills training; however, the change of surgical configuration, from conventional laparoscopy to LESS setup, did prove to be a challenge in the process of acquiring LESS skills and competence of the participants. We believe that this finding was due to the ergonomic differences that exist between both surgical configurations, as LESS technique spatial location of instruments within the abdominal cavity is more complex, which does not allow for completely transfer the skills acquired in the traditional surgical technique and vice versa. However, more studies will be done to confirm this hypothesis.

Regarding the configuration of instruments for the acquisition of surgical skills, a previous study evaluated the relative technical difficulty and performance of articulating and curved instruments, combined or not with conventional laparoscopic tools, during the performance of two basic simulator tasks for LESS surgery[22,23]. This study showed a significant improvement in the quality of surgical performance and execution time in basic simulator coordination tasks after LESS training using a combination of articulating and conventional straight instruments compared to both articulating instruments. The EAES consensus statement on single-incision endoscopic surgery also recommended the use of a combination of one straight and one articulating/curved instrument during the learning curve of LESS surgery. Therefore, as a further study, it would be worthwhile to comprehensively analyze the effect of LESS surgery training on the use of articulating instruments in comparison with the combination of articulating and flexible instruments, including more advanced tasks such as intracorporeal suturing. As we have observed with Group-A of the present study, the inclusion in the LESS surgery training program of conventional laparoscopic training does not seem to present a significant improvement in surgical skills, except in bimanual dexterity. Other studies have also shown that previous experience in laparoscopic surgery does not lead to a significant improvement in the quality of surgical performance after training in LESS surgery[24].

Our study had some limitations, such as the use of only one type of access port for LESS surgery. For this investigation, we chose the Medtronic SILS™ single port due to its ease of adaptation to the laparoscopic box trainer and the video-based motion tracking system employed in this study. Although we believe that this decision did not generate a significant impact on surgical performance or alter the learning curve of the participants, in future work we will study the use of other commercial devices (e.g., XCone and GelPoint) and their combination with different types of instruments for LESS surgery (straight and articulating). Another limitation of our study is found in the post-training evaluation of the three groups, where LESS surgery configuration and articulating instruments were used to evaluate the skills and technical competence of the participants at the end of the study. We believe that this method could put Group-C at an advantage because they had the opportunity to practice in this surgical configuration for longer, obtaining better results in the post-training evaluation. In future work, we will evaluate the acquisition of laparoscopic MIS skills by combining in the final evaluation the two surgical configurations (conventional laparoscopy and LESS surgery) with both types of instruments (straight and articulating) and different training tasks in all study groups to assess the level and quality achieved of these skills learned through their type of assigned training. We will also study the introduction of a specialized training program for LESS surgery in the training curriculum of surgical residents and its impact on conventional laparoscopic surgical skills. Another important aspect to investigate will be possible improvements in the design of instruments for LESS surgery that improve surgical performance and surgeon ergonomics, as well as the creation of specific tasks that help in the acquisition of surgical skills and abilities in LESS surgery.

Further research is still required in aspects concerning the quality and structure of training. In this sense, this study did not include outcome measures of the task but rather relied on motion analysis of laparoscopic instruments, which has been linked to surgical skills[25,26]. Furthermore, future studies should consider aspects related to skill retention to design and structure training programs; in this sense, several studies have shown that spacing of the training can increase its effectiveness on skills' acquisition and retention[27]. In our study, the intensity of training was equal for all three groups and massed in 12 days. Future studies will be planned considering different temporal spans for training and measuring skill retention at different moments after completing the program.

Conclusions

The study demonstrated that dedicated training in LESS surgery settings with articulating laparoscopic instruments improves the quality of skills and the performance of the surgeons, reflected in an overall improvement in MAPs. Training with different surgical configurations, conventional laparoscopy, and single-port surgery, improves the ability to control both instruments in a coordinated manner, particularly the surgeons' bimanual dexterity. Prolonged use of articulating laparoscopic instruments in this LESS surgery setting demonstrated a more efficient learning curve, with rapid adaptation to the reduced working space, resulting in a similar and smooth performance for all three training tasks. Overall, the results of this study suggest that structured laparoscopic skills training in LESS surgery should be included in existing surgical residency curricula to enhance the education of residents in conventional and LESS surgery. This training program would improve their skills in instrument handling and triangulation, hand-eye coordination, and a two-dimensional view of the operative field.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical disclosures

Protection of humans and animals. The authors declare that no experiments on humans or animals were performed for this research.

Confidentiality of data. The authors declare that they have followed their center's protocols for the publication of patient data.

Right to privacy and informed consent. The authors have obtained the informed consent of the patients and/or subjects referred to in the article. This document is in the possession of the corresponding author.

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