Cir Pediatr. 2021; 34: 20-27

Laparoscopic learning curves

D. Peláez Mata[1], S. Herrero Álvarez[2], A. Gómez Sánchez[3], L. Pérez Egido[1], C. Corona Bellostas[4], J.C. de Agustín Asensio[1]

[1]Pediatric Surgery Department. Gregorio Marañón Pediatric Hospital. Madrid (Spain). [2]Maxillofacial Surgery Department. San Carlos Clinical Hospital. Madrid (Spain). [3]Traumatology Department. 12 de Octubre Hospital. Madrid (Spain). [4]Pediatric Surgery Department. Miguel Servet Hospital. Zaragoza (Spain).

ABSTRACT

Objectives. Laparoscopic learning curves are slow, and there are no uniform surgical skill acquisition models. Therefore, our objective was to assess a laparoscopic skill learning program in individuals without any surgical experience, analyzing the learning curve by means of a certified custom-made simulator, and evaluating whether previous surgical experience had an impact on the learning curve.

Materials and methods. A certified custom-made simulator and laparoscopic instruments were used to assess 20 university students who performed 10 repetitions of 3 exercises of growing difficulty (eye-hand coordination, hand-hand coordination, and cutting). Three parameters were analyzed: total time with each hand, total mistakes with each hand, and three items of the OSATS technical skill scale. The two first exercises were compared with a group of 14 experienced surgeons. Statistical analysis using repeated-measures Anova and Student's t-test was carried out ($p < 0.05$).

Results. Significant time improvement with each repetition was demonstrated in the three exercises. Curve stabilization was faster in surgeons (2-4 repetitions) than in students (8-9). Time reduction was noted in the first and second exercises in both groups, with 44.08% and 33.1% shorter times, respectively.

Conclusions. Individuals without surgical experience acquired basic laparoscopic skills using a custom-made simulator, which allows simple surgical techniques to be carried out in an inexpensive, accessible fashion. Previous surgical experience was associated with a shorter learning curve. The custom-made simulator allowed individuals with and without surgical experience to be distinguished from each other.

KEY WORDS: Laparoscopy; education; Learning curve; Simulation; Training.

Corresponding author: Dr. Dr. David J. Peláez Mata. C/ Fortunata y Jacinta, 7 - 7º C. 28020 Madrid.
E-mail address: david.pelaez@salud.madrid.org

Date of submission: May 2020 *Date of acceptance:* September 2020

CURVAS DE APRENDIZAJE EN LAPAROSCOPIA

RESUMEN

Objetivos. La curva de aprendizaje en cirugía laparoscópica es lenta y no existen modelos uniformes de adquisición de habilidades quirúrgicas. Tratamos de establecer la idoneidad de un programa de aprendizaje de habilidades laparoscópicas en sujetos sin experiencia quirúrgica, analizando la curva de aprendizaje utilizando un simulador artesanal homologado. Comprobar si la experiencia quirúrgica previa modifica la curva de aprendizaje.

Material y métodos. Se empleó un simulador artesanal validado e instrumental laparoscópico para evaluar a 20 estudiantes universitarios que realizaron 10 repeticiones de tres ejercicios de dificultad creciente (coordinación ojo-mano, coordinación mano-mano y corte). Se evaluaron tres parámetros: tiempo total y con cada mano, errores totales y con cada mano y tres ítems de habilidad técnica OSATS. Comparación de los dos primeros ejercicios con un grupo de 14 cirujanos con experiencia. Análisis estadístico mediante Anova para medidas repetidas y t de Student ($p < 0,05$).

Resultados. Se demostró la mejoría significativa del tiempo con cada repetición en los tres ejercicios. La estabilización de la curva fue más precoz entre los cirujanos (2-4 repeticiones) que los estudiantes (8-9). Se comprobó la reducción del tiempo invertido para el primer y segundo ejercicio en ambos grupos, que en los estudiantes fue del 44,08% y 33,1% respectivamente.

Conclusiones. Individuos sin experiencia quirúrgica desarrollan habilidades laparoscópicas básicas utilizando un simulador artesanal, que permite practicar técnicas quirúrgicas sencillas de forma barata y accesible. La experiencia quirúrgica previa se asocia con el acortamiento de la curva de aprendizaje. El simulador artesanal permite discriminar entre sujetos con y sin experiencia quirúrgica.

PALABRAS CLAVE: Laparoscopia; Educación; Curva de aprendizaje; Simulación entrenamiento.

INTRODUCTION

Laparoscopy is the technique of choice for multiple procedures, both in adults and in children, with exponentially growing importance[1,2]. Advantages over conventional open surgery are widely known: better operating field visualization, fewer surgical wound complications, less postoperative pain, shorter postoperative recovery (thus making hospital stay shorter, too), and better esthetic results[2,3]. In pediatric surgery, the introduction of laparoscopy has taken longer as a result of the lack of instruments adapted to pediatric patients and the lower number of surgical patients, which implies a slower learning curve[2].

The learning curve is a graphic representation of how many times a certain procedure needs to be repeated before the skills necessary to perform it in an adequate and safe manner are acquired. Curve inclination varies according to individuals and procedures[3]. In laparoscopy, the learning curve is more complex, slower, and more prone to mistakes than in open surgery. This can be explained by various factors, such as shortage of procedures suitable for training purposes, difficulty of video-eye-hand coordination, loss of third dimension and touch, and fulcrum effect, which inverts instrument motion and increases trembling[1,4]. For greater patient safety, the learning curve should not be based on the trial-and-error experience acquired at the operating room only, but training should be initiated outside clinical practice[4,5].

There is no uniform laparoscopic skill acquisition model available[6]. Traditionally, skills have been acquired by means of intensive hands-on courses[5], but there are various laparoscopic surgical simulators designed for learning at all levels[7]. They may use live (anesthetized animals) or inert (human or animal corpses, virtual reality, synthetic simulators, and custom-made simulators) systems. The objective is to create a realistic environment allowing laparoscopic skills to be reproduced outside the operating room in a safe and ethical manner, with time and cost being the only limitations[7]. In addition, these simulators are not only useful for initial laparoscopic learning, but also for technical skill improvement in experienced surgeons.

The objective of this study was to assess a structured training program for the acquisition of basic laparoscopic skills in individuals without surgical experience by analyzing the learning curve using a certified custom-made simulator[1]. To verify whether previous surgical experience had an impact on the laparoscopic learning curve, the curves from the non-experienced group were compared with those from the experienced surgeon group.

MATERIALS AND METHODS

For surgical skill assessment, a custom-made simulator was used, and exercises were designed with growing levels of difficulty (Fig. 1).

Custom-made simulator and exercise plates

The simulator was made up of a 38 x 27 x 20 cm translucent plastic box with a 30-degree inclined inner wood panel, on which two Velcro straps were adhered for plate fixation purposes. Exercise plates were interchangeable (Fig. 1D). A webcam was placed on the box lid, centered with respect to the instrument orifices, and a fluorescent was installed for lighting purposes. The image was achieved using a personal computer connected to the camera. Interchangeable plates, fixated on the simulator's inclined panel, were used, with a rubber surface allowing three exercises of growing difficulty to be carried out: eye-hand coordination, hand-hand coordination, and cutting.

Figure 1. Custom-made simulator and exercise plates. A) Eye-hand coordination. B) Hand-hand coordination. C) Cutting. D) Final look of the custom-made simulator.

The instruments used included "crocodile" grasping forceps, dissecting forceps, and 5 mm diameter scissors.

Exercise assessment

Each participant performed 10 repetitions of each exercise in the custom-made simulator. A growing difficulty order was followed: eye-hand coordination, hand-hand coordination, and cutting. The 10 repetitions had to be completed before moving on to the next exercise. Exercise assessment was based on three parameters: time in minutes, number of mistakes, and the first three items of the OSATS (Objective Structured Assessment of Technical Skills[8]) scale, measured by the primary researchers (S.H.A. and A.G.S.) and supervised by the main author. Each exercise's score was assessed while adding a 10-second penalty per mistake to final time.

Eye-hand coordination ("stones")

Four little transparent plastic boxes fixated to the surface were placed on the exercise plate. Three of them were colored red, blue, and green, respectively, and the fourth was filled with irregular stones of the aforementioned colors. Two "crocodile" grasping forceps were used (Fig. 1A).

The exercise was initiated with all color stones mixed in the container located closest to the camera. Participants had to move the stones to the containers of the same color using their right hand, and then move them back to the initial container using their left hand. 10 repetitions were carried out before moving on to the next exercise.

At each repetition, total time in minutes, time spent with each hand, and number of falling stones (total and with each hand) were recorded. A total score was achieved while adding a 10-second penalty per mistake to final time, and the second and third items of the OSATS scale (time and motion; instrument handling) were assessed.

Hand-hand coordination ("rings")

Four nails of various lengths were fixated on the base of the exercise plate, and several rubber rings of three different diameters were placed on it. Two dissecting forceps were used in this exercise (Fig. 1B).

All rings of different sizes were placed on the nail located closest to the camera. Participants had to grasp the rings with their right hand, move them in the air to their left hand, and place them on the different nails according to size – the big rings on the big nail, the medium rings on the medium nail, and the small rings on the small nail. Once the rings had been adequately placed, participants had to move them back to the initial nail by grasping them with their left hand and transferring them to their right hand. 10 repetitions were carried out before moving on to the next exercise.

At each repetition, total time in minutes and the number of falling rings with each hand and during hand-to-hand transfer were recorded. A total score was achieved while adding a 10-second penalty per mistake to final time, and the second and third items of the OSATS scale (time and motion; instrument handling) were assessed.

Cutting

The exercise plate was prepared with a gauze anchored to the rubber sheet, on which a 5 cm diameter circle was drawn with a marker. The instruments used included a dissecting forceps and a pair of laparoscopic scissors (Fig. 1C).

Participants had to cut out the border of the circle while following the line. They used their right hand to cut the right half of the circle, and their left hand to cut the left half of the circle. 10 repetitions were carried out. At each repetition, total time in minutes, time spent with each hand, and number of cuttings not following the line – total and with each hand – were recorded. A total score was achieved while adding a 10-second penalty per mistake to final time, and the first, second, and third items of the OSATS scale (respect for tissue; time and motion; instrument handling) were assessed.

Asymptote

Learning curve stabilization was statistically represented for each exercise.

Study individuals

20 individuals without surgical experience were selected. They were personally monitored for learning curve drawing and analysis purposes.

In the eye-hand coordination and hand-hand coordination exercises, sample results were compared with those achieved by 12 specialist pediatric surgery physicians and 5 fellows from the pediatric surgery department at our healthcare facility. Of them, 7 had performed more than 50 laparoscopic procedures as surgeons and more than 100 as assistants, and 10 had conducted less than 50 laparoscopic procedures as surgeons and less than 100 as assistants (data from Carolina Corona Bellostas' *Contribution to learning curve analysis in laparoscopic surgery* doctoral thesis[1]).

Statistical analysis

The SPSS 15 for Windows statistical package was used. Results were considered statistically significant at $p < 0.05$. In the general analysis of the learning curve, a repeated-measures Anova test was used in order to demonstrate significant learning improvement at each exercise. For asymptote study purposes, a Student's t-test applied to mean total time and mean total score for each repetition was carried out.

RESULTS

20 medical students without previous surgical experience were selected: 8 first-year students (40%), 6 fourth-year students (30%), and 6 sixth-year students (30%). 13 participants (63%) were female and 7 participants were male, with a mean age of 21.2 years (range: 18-28 years). All participants were right-handed.

General analysis of the learning curve

Eye-hand coordination ("stones")

Statistically significant improvement with each repetition was noted in total time and time spent with each hand (Table I), number of mistakes with the right hand (Table II), total score (Fig. 2), and OSATS scale items 2 and 3. No statistically significant differences were found when analyzing the total number of mistakes and the number of mistakes with the left hand at each repetition (times and mistakes with each hand are featured in table III).

Hand-hand coordination ("rings")

Statistically significant improvement with each repetition was noted in total time and time spent with each

Table I. Mean time for each exercise repetition (in minutes:seconds).

Number of repetitions	*Eye-hand coordination ("stones")*	*Hand-hand coordination ("rings")*	*Cutting*
1	5:38 ± 1:56	6:41 ± 1:14	6:42 ± 2:39
2	4:48 ± 1:37	6:26 ± 1:31	5:01 ± 1:35
3	4:28 ± 1:06	5:39 ± 1:06	4:54 ± 1:30
4	3:59 ± 1:11	5:25 ± 1:25	4:42 ± 1:29
5	3:53 ± 1:06	5:15 ± 0:50	4:14 ± 1:08
6	3:31 ± 5:38	5:21 ± 1:02	4:07 ± 1:13
7	3:39 ± 0:53	4:53 ± 0:54	4:00 ± 0:57
8	3:28 ± 0:47	4:53 ± 0:47	3:42 ± 0:56
9	3:23 ± 0:50	4:30 ± 0:54	3:43 ± 1:01
10	3:09 ± 0:51	4:24 ± 0:45	3:36 ± 0:46
p	<0.05	<0.05	<0.05

Table II. Mean number of mistakes for each exercise repetition (in minutes:seconds).

Number of repetitions	*Eye-hand coordination ("stones")*	*Hand-hand coordination ("rings")*	*Cutting*
1	4.65 ± 3.17	3.80 ± 2.59	6.25 ± 1.71
2	3.85 ± 1.81	3.70 ± 2.13	5.15 ± 1.53
3	4.00 ± 2.22	3.15 ± 2.37	3.85 ± 1.49
4	3.40 ± 1.54	2.75 ± 2.29	3.95 ± 1.39
5	2.65 ± 1.81	2.10 ± 1.62	3.35 ± 1.31
6	2.60 ± 2.01	2.50 ± 1.70	3.40 ± 1.46
7	2.50 ± 1.36	2.20 ± 1.77	3.45 ± 1.35
8	2.10 ± 1.62	2.40 ± 1.93	3.75 ± 1.37
9	2.40 ± 1.35	2.65 ± 2.30	3.00 ± 1.12
10	2.95 ± 1.79	2.50 ± 1.96	3.50 ± 1.23
p	0.221	0.087	<0.05

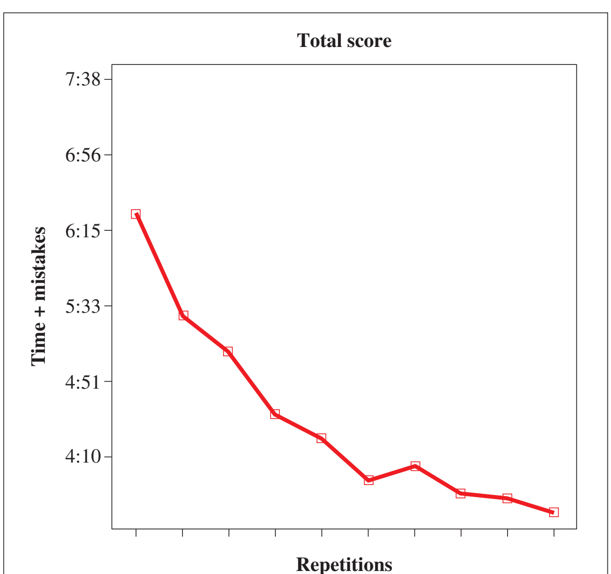

Figure 2. Eye-hand coordination ("stones") score in minutes and seconds (total time and 10-second penalty per mistake) at each repetition.

hand (Table I), total score (Fig. 3), and OSATS scale items 2 and 3. No statistically significant differences with each repetition were found in the number of mistakes during hand-to-hand transfer or in the total number of mistakes (Table II).

Cutting

Significant improvement with each repetition was found across all variables analyzed (Fig. 4).

Surgeon-student comparative study

The results from our eye-hand coordination and hand-hand coordination exercises were compared with those achieved by expert surgeons in the same exercises[1] (Fig. 5).

Eye-hand coordination ("stones")

Mean time at baseline and mean time at the last repetition were shorter in the surgeon group than in the student group, but student mean final time was shorter than surgeon mean baseline time. Time reduction was similar in both groups (Table IV).

Table III. Time (in minutes:seconds) and number of mistakes with each separate hand in the eye-hand coordination exercise.

Number of repetitions	*Right hand time*	*Left hand time*	*Right hand mistakes*	*Left hand mistakes*
1	3:05	3:36	2.8	3.45
2	2:03	2:58	2.8	2.85
3	1:54	2:59	1.5	2.35
4	1:54	2:47	1.8	2.15
5	1:45	2:29	1.6	1.75
6	1:50	2:17	1.7	1.9
7	1:46	2:14	1.55	1.9
8	1:33	2:08	1.5	2.25
9	1:31	2:12	1.35	1.65
10	1:26	2:04	1.55	1.95
p	<0.05	<0.05	<0.05	0.3

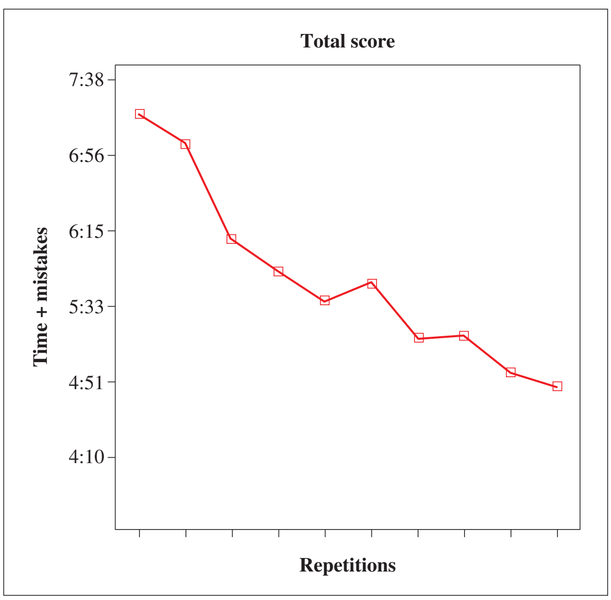

Figure 3. Hand-hand coordination (“rings”) score in minutes and seconds (total time and 10-second penalty per mistake) at each repetition.

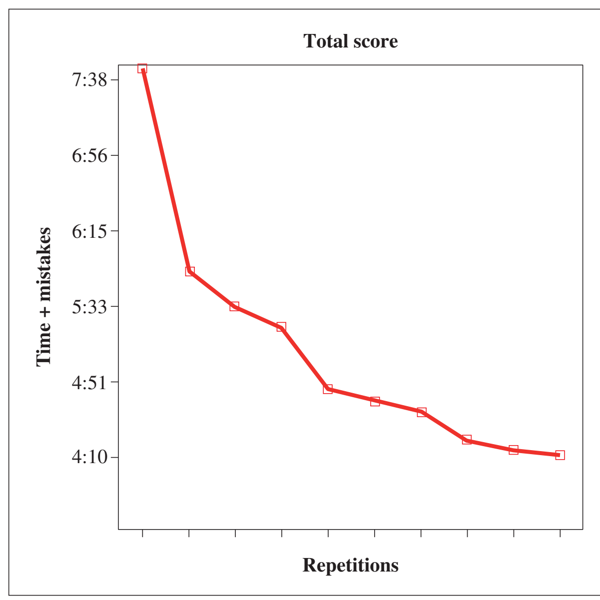

Figure 4. “Cutting” score in minutes and seconds (total time and 10-second penalty per mistake) at each repetition.

Hand-hand coordination (“rings”)

Mean time at baseline and mean time at the last repetition were shorter in the surgeon group. Student mean final time was longer than surgeon mean baseline time. Time reduction was greater in students than in surgeons (Table IV).

Asymptote study (Fig. 5)

Eye-hand coordination (“stones”)

Total time curve stabilization was achieved following 4 repetitions in the surgeon group, and following 9 repetitions in the student group.

Hand-hand coordination (“rings”)

Total time curve stabilization was achieved following 2 repetitions in the surgeon group, and following 9 repetitions in the student group.

DISCUSSION

In order not to violate the ethical principle of non-maleficence, training methods are developed outside surgical practice, which prevents patients from being used as a single learning method[9-11]. Surgical practice with simulators flattens the learning curve and has been demonstrated to

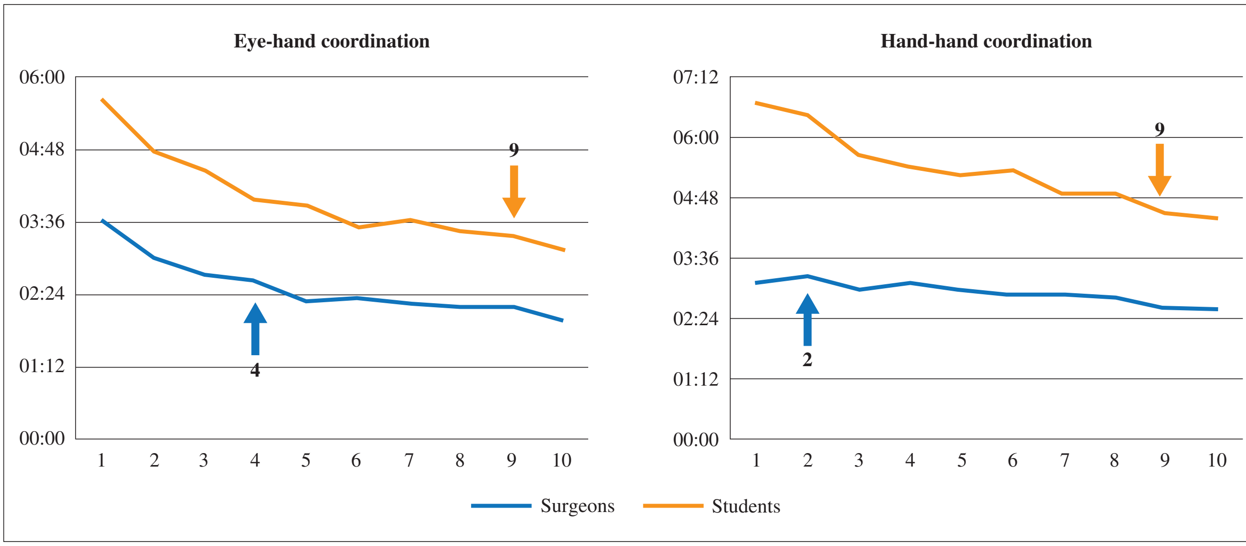

Figure 5. Comparison of surgeon and student total time (minutes and seconds) in the eye-hand coordination (stones) and hand-hand coordination (rings) exercises. The asymptote is included in the four curves.

Table IV. Comparison of time reduction in minutes and seconds for each exercise in each group (surgeons and students).

Exercise	*Group*	*Baseline time*	*Final time*	*Time reduction*
Eye-hand coordination ("stones")	Surgeons	3:37	1:58	45.62%
	Students	5:38	3:09	44.08%
Hand-hand coordination ("rings")	Surgeons	3:07	2:36	16.58%
	Students	6:41	4:24	33.17%

reduce the likelihood of intraoperative complications in the future[12,13].

The usefulness of commercial and custom-made simulators in minimally invasive surgery has been proven by multiple studies comparing custom-made systems with commercial pelvitrainers[14]. These studies have also demonstrated that laparoscopic training customized boxes involve lower costs than commercial simulators, with the additional advantage of being simple, accessible devices that can be used anywhere[4,15]. The simulator used in our study had been certified in a previous work carried out at the same healthcare facility[1].

Learning programs should consist of exercises of growing difficulty and structured systems allowing for laparoscopic skill acquisition by surgeons and students alike. Preclinical structured training (last-year students and fellows) has proved superior to assisted clinical training and clinical training combined with simulation[16].

Our study confirmed that individuals without surgical experience are able to learn basic laparoscopic techniques. The analysis of the total score curve demonstrated that repetitions allowed for shorter exercises and fewer mistakes. When separately analyzing both variables, significant improvement in terms of total time was noted in all exercises, but significant improvement in terms of mistakes was only recorded in the third exercise ("cutting") and not in the two first exercises (coordination exercises). This could be explained by the fact individuals initially prioritize time reduction over minimizing the number of mistakes. Previous experience may allow individuals to significantly reduce not only time, but also the number of mistakes in the third exercise. The fact a right-handed student cohort was used could account for the fact that, even though time improvement was achieved with each hand separately, baseline and final times were shorter with the right hand than with the left hand.

The OSATS (Objective Structured Assessment of Technical Skills) scale assesses surgical apprentices' technical skills by evaluating 7 items with a score ranging from 1 to 5 during various structured surgical tasks[8]. Improvement in OSATS scale parameters was noted in the 3 exercises.

Students learnt how to handle laparoscopic devices they were not previously familiar with, but without reaching high skill levels (maximum score: 3 out of 5).

Surgical experience has been demonstrated to reduce the learning curve. In the surgeon group, curve stabilization was achieved in the first 3-4 repetitions, whereas students required 8-9 repetitions (Fig. 5). Student learning curve may improve with further repetitions, thus allowing for greater stabilization.

In the two exercises assessed, surgeons had shorter baseline and final times than students. Indeed, surgical experience contrasts with how little familiar students are with laparoscopic instruments and operating field visualization on a screen. In the eye-hand coordination exercise, student final time was shorter than surgeon baseline time, with time reduction being similar in both groups (Fig. 5A). In the hand-hand coordination exercise, student final time was longer than surgeon baseline time. This can be explained by the fact the second exercise was more complex than the first. In spite of this, time reduction in the second exercise was significantly greater in the student group, which means surgeons find it harder to reduce time than students (Fig. 5B). This can be explained by the fact surgeon times are already short and therefore hard to improve, whereas student baseline times can be more easily reduced throughout repetitions. In addition, the custom-made simulator used in this study was able to distinguish individuals with experience in laparoscopic surgery from individuals without it, consistent with previous studies[17].

One of the main limitations our study has lies in the fact that the OSATS scale was applied by medical students, not by specialist surgeons. Current simulators require expert surgeon supervision for skill acquisition and assessment purposes[18].

Further studies evaluating surgeon cutting skills should be carried out. The study of the student learning curve could also be enhanced by assessing other basic skills such as knots and sutures, and subsequently, by using animal models for more complex skill acquisition[19]. Furthermore, students with greater exposure to videogames had better eye-hand coordination[3]. Knowing how many hours students devote to playing videogames could allow us to assess whether this proves advantageous for exercise completion or not.

In conclusion, it has been proved that a group of individuals without surgical experience can learn about basic laparoscopic techniques using a custom-made simulator. The comparative study demonstrated differences in terms of performance according to previous surgical experience, which allows for a shorter learning curve. The custom-made simulator proved effective in distinguishing individuals with surgical experience from individuals without it.

REFERENCES

1. Corona C. Contribución al análisis de curvas de aprendizaje en cirugía laparoscópica [tesis doctoral]. Zaragoza: Universidad de Zaragoza, Departamento de Anatomía e Histología Humanas; 2015.
2. Laufer MR, Reichman DE, Smithers CJ. Overview of laparoscopy in children and adolescents. Uptodate [revista electronica]. Sep 2016. Disponible en: https://www.uptodate.com/contents/overview-of-laparoscopy-in-children-and-adolescents
3. Borahay MA, Jackson M, Tapisiz OL, Lyons E, Patel PR, Nassar R, et al. Assessment of minimally invasive surgical skills of pre-medical students: What can we learn from future learners? J Turk Ger Gynecol Assoc. 2014; 15(2): 69-73.
4. Köckerling F, Pass M, Brunner P, Hafermalz M, Grund S, Sauer J, et al. Simulation-Based Training - Evaluation of the Course Concept "Laparoscopic Surgery Curriculum" by the Participants. Front Surg. 2016; 3(47): 1-7.
5. De Win G, Van Bruwaene S, Kulkarni J, Van Calster B, Aggarwal R, Allen C, et al. An evidence-based laparoscopic simulation curriculum shortens the clinical learning curve and reduces surgical adverse events. Adv Med Educ Pract. 2016; 7: 357-70.
6. Enciso S, Díaz-Güemes I, Usón J, Sánchez-Margallo FM. Validación de un modelo de formación intensiva en cirugía digestiva laparoscópica. Cir Esp. 2016; 94(2): 70-6.
7. Caban AM, Guido C, Silver M, Rossidis G, Sarosi G, Ben-David K. Use of collapsible box trainer as a module for resident education. JSLS. 2013; 17(3): 440-4.
8. Martin JA, Regehr G, Reznick R, McRae H, Murnaghan J, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. Br J Surg. 1997; 84: 273-8.
9. Jara Rascón J, Subirá Ríos D. Ética y aprendizaje en cirugía laparoscópica. Actas Urol Esp. 2006; 30(5): 474-8.
10. Nácul M, Cavazzola L, Melo M. Current status of residency training in laparoscopic surgery in Brazil: a critical review. Arq Bras Cir Dig. 2015; 28(1): 81-5.
11. García-Murillo J, Arias-Correa M, Valencia-Díaz E. Diseño de prototipo de simulador para entrenamiento en cirugía laparoscópica. Rev Ing Biomed. 2011; 5(9): 13-9.
12. Hernández-Fernández C. Finalidad de los cursos de adiestramiento práctico. Actas Urol Esp. 2006; 30(5): 461-3.
13. Benito Expósito P, Ortiz Oshiro E, Ramos Carrasco A, Ortega López D, Hernández-Pérez C, Pardo-Martínez C, et al. Formación estructurada en cirugía mínimamente invasiva para residentes quirúrgicos [revista electrónica]. 2016. Disponible en: http://www.seclaendosurgery.com/index.php?option=com_content&view=article&id=170 &Itemid=168
14. Chung SY, Landsittel D, Chon CH, Ng CS, Fuchs GJ. Laparoscopic skills training using a webcam trainer. J Urol. 2005; 173(1): 180-3.
15. Lopes-Salazar A, Ramírez M, Ruiz Cerdá JL. Modelos artesanales de simulación para el aprendizaje laparoscópico. Actas Urol Esp. 2006; 30(5): 457-60.
16. De Win G, Van Bruwaene S, Aggarwal R, Crea N, Zhang Z, De Ridder D, et al. Laparoscopy training in surgical education: the utility of incorporating a structured preclinical laparoscopy course into the traditional apprenticeship method. J Surg Educ. 2013; 70(5): 596-605.

17. Morandeira Rivas A, Cabrera Vilanova A, Sabench Pereferrer F, Henández González M, Del Castillo Déjardin D. Simulador de bajo coste para el entrenamiento de habilidades laparoscópicas básicas. Cir Esp. 2010; 87(1): 26-32.
18. Singapogu R, Burg T, Burg KJ, Smith DE, Eckenrode AH. A perspective on the role and utility of haptic feedback in laparoscopic skills training. Crit Rev Biomed Eng. 2014; 42(3-4): 299-318.
19. Pérez Duarte FJ, Díaz Guemes I, Sánchez Hurtado MA, Cano-Novillo I, Berchi García FJ, García Vázquez A, et al. Diseño y validación de un programa formativo en cirugía laparoscópica pediátrica y neonatal. Cir Pediatr. 2012; 25: 121-5.