Int J CARS (2012) 7:305–313
DOI 10.1007/s11548-011-0650-9

ORIGINAL ARTICLE

Decomposition and analysis of laparoscopic suturing task using tool-motion analysis (TMA): improving the objective assessment

J. B. Pagador · F. M. Sánchez-Margallo · L. F. Sánchez-Peralta · J. A. Sánchez-Margallo · J. L. Moyano-Cuevas · S. Enciso-Sanz · J. Usón-Gargallo · J. Moreno

Received: 10 January 2011 / Accepted: 2 August 2011 / Published online: 14 August 2011

Abstract
Purpose The laparoscopic suturing task is a complex procedure that requires objective assessment of surgical skills. Analysis of laparoscopic suturing task components was performed to improve current objective assessment tools.
Methods Twelve subjects participated in this study as three groups of four surgeons (novices, intermediates and experts). A box-trainer and organic tissue were used to perform the experiment while tool movements were recorded with the augmented reality haptic system. All subjects were right-handed and developed a surgeon's knot. The laparoscopic suturing procedure was decomposed into four subtasks. Different objective metrics were applied during tool-motion analysis (TMA). Statistical analysis was performed, and results from three groups were compared using the Jonckheere–Terpstra test, considering significant differences when $P \leq 0.05$.
Results Several first, second and fourth subtask metrics had significant differences between the three groups. Subtasks 1 and 2 had more significant differences in metrics than subtask 4. Almost all metrics showed superior task executions accomplished by experts (lower time, total path length and number of movements) compared with intermediates and novices.
Conclusion The most important subtasks during suture learning process are needle puncture and first knot. The TMA could be a useful objective assessment tool to discriminate surgical experience and could be used in the future to measure and certify surgical proficiency.

Keywords Laparoscopic suturing · Objective assessment · Tool-motion analysis · TMA · Augmented reality haptic · ARH · Minimally invasive surgery

Introduction

Laparoscopic surgery can be considered as one of the most important advances in the field of surgery in the last 20 years. It can be used in many surgical techniques because it provides multiple safety advantages for patients [1,2] and important health cost reductions [3]. Nevertheless, it requires some specific knowledge and psychomotor skills that make necessary a specific training program for surgeons [4,5]. This study is focused on laparoscopic suture because it can be considered as one of the most complex surgical procedures. Therefore, a complete and detailed analysis of decomposition in subtask of the whole suturing procedures was performed.

Different kinds of simulators have been used to train suture skills in the last years [6]. Traditionally, surgical simulators were divided between physical simulators (box-trainers) and virtual reality simulators. Box-trainers can be distinguished for its low cost, high realism and simple maintenance, but they usually are limited to simple procedures, require a subjective evaluation of the exercises with a few set of available

J. B. Pagador (✉) · L. F. Sánchez-Peralta · J. A. Sánchez-Margallo · J. L. Moyano-Cuevas
Bioengineering and Health Technologies Unit, Jesús Usón Minimally Invasive Surgery Centre, Cáceres, Spain
e-mail: jbpagador@ccmijesususon.com

S. Enciso-Sanz
Laparoscopic Unit, Jesús Usón Minimally Invasive Surgery Centre, Cáceres, Spain

F. M. Sánchez-Margallo · J. Usón-Gargallo
Direction, Jesús Usón Minimally Invasive Surgery Centre, Cáceres, Spain

J. Moreno
Laboratory of Robotics and Artificial Vision, University of Extremadura, Cáceres, Spain

metrics [7]. In the other hand, virtual reality simulators offer an extended set of objective metrics that can be automated and obtained without needing of an expert revising the tasks [8]. Tutorials and mentoring guides can be introduced in virtual reality simulators to improve the learning process and enrich available resources for surgeons [9]. However, their high cost makes difficult that they can be widely extended over the world. Furthermore, they have not overcome the lack of realism due to technical or technological limitations (maybe haptic feedback is the most important problem at the moment) [10]. Nowadays, a hybrid approach that uses different computer science technologies (computer graphics, augmented reality, tracking systems among others) are making a new generation of surgical simulators. These hybrid simulators or computer-enhanced simulators aim to improve box-trainers with computers [11] or robotic systems [12,13] that include some of the virtual reality simulators features as the objective assessment.

The objective assessment of surgical proficiency and skills has been the subject of numerous studies [14]. The objective structured assessment of technical skills (OSATS) and the objective structured clinical examination (OSCE) have been used from the late 80s and early 90s, while a few years later the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS) program was developed. The MISTELS program was used for the SAGES to create the Fundamentals of Laparoscopic Surgery (FLS) that regulate the laparoscopic training in the US [5]. However, an expert was usually required for the application of all techniques described previously until different computer or robotic systems were included to automate them.

The Imperial College Surgical Assessment Device (ICSAD) and the Advanced Dundee Endoscopic Psychomotor Tester (ADEPT) were two of the first systems developed to automate the objective assessment of surgical skills [14]. They were used to train and evaluate real procedures [15,16]. More tracking systems were developed after these ones [9,17–20] what assures the usefulness of tracking to evaluate surgical skills. However, some studies use surgical proficiency checklists [15,21], video-based techniques [22,23] or robotic systems [12,13] to improve the training quality with a feedback for surgeons and an evaluation report with additional information.

The ICSAD device has been used in many studies of hand-motion analysis (HMA) for both open and minimally invasive surgery [15,16]. However, the use of tool-motion analysis (TMA) which analyzes the tooltip movements instead of the hand movements would enhance the objective assessment for laparoscopic procedures with a more accurate tracking of the instrumental.

In this study, TMA is used to evaluate the surgical skills for different subtasks of the laparoscopic suturing procedure. For this reason, the laparoscopic suture has been decomposed into four subtasks to perform an in-depth analysis of the training suturing process and demonstrate the use of TMA as assessment and certification tool of surgical skills.

Materials and methods

The present study uses the tool-motion analysis (TMA) to improve the objective assessment of laparoscopic suturing skills. In order to do this, a decomposition of the whole suture procedure was performed and an individual analysis of each subtask was realized. This decomposition was manually accomplished by an expert surgeon who watched the videos.

Subjects

The total number of recruited participants in the study was twelve. The subjects were divided into three groups according to their experience in laparoscopic surgery. Group 1 was composed by four novices, group 2 comprised four intermediates, and group 3 was formed by four experts. All participants in the study were right-handed.

All tests were accomplished in the Jesús Usón Minimally Invasive Surgery Centre in Cáceres, Spain. Experts had experience of more than 50 cases in laparoscopic surgery and are experienced teachers at suturing courses. Intermediate surgeons had performed between 10 and 50 laparoscopic procedures and are assistants at suturing courses. And finally, all novices had attended laparoscopic procedures with minimal hands-on experience in camera guidance and have no experience on suturing tasks.

Methodology

A surgeon's knot was the selected task to perform this study [4]. It was carried out using the Simulap-IC05 box-trainer and an organic tissue (carcass stomach) in order to reproduce as much as possible an actual suturing task within a safe and reproducible environment. The augmented reality haptic (ARH) was used to record the surgical gestures of surgeons [20]. This system consists of an electromagnetic tracking device located over the tool handle that can determine the position of the tip of the surgical instruments.

The whole procedure was divided during the TMA into 4 subtasks to understand this complex task and obtain the most relevant subtask during the learning process. These subtasks are:

Subtask 1: *Needle puncture* This first step comprises setting the needle orientation (90 degree angle) in the needle-holder before performing the puncture over the wound edge. The needle must go through the two parts of the wound.

Subtask 2: *First knot* (*double*) After locating the surgical thread with the proper length, the nondominant tool must

grasp the thread to facilitate the double looping (counter-clockwise) that must be performed by the dominant tool. Finally, the knot must be tightened with both tools.
Subtask 3: *Second knot* (*single*) A single clockwise knot that needs to prepare the surgical thread, to make a single loop and then to tighten the knot.
Subtask 4: *Third knot* (*single*) This is the last phase where a single counter-clockwise knot (with its three steps) must be performed.

Different objective metrics were automatically recorded using the ARH system for the whole laparoscopic suture procedure. Then, a manual decomposition of the whole procedure into the 4 subtasks was performed by an experienced surgeon. Finally, a TMA technique was used to obtain the results with the selected metrics that are defined as follows:

– *Total time* Elapsed time before the surgeon can accomplish the subtask.
– *Total path length* Path used by the tooltip to perform the subtask.
– P*artial path length* Mean path that the user moves the tooltip at the data acquisition rate of the ARH system (approx. 30 Hz).
– *Average speed* Mean of the tooltip speed obtained at the data acquisition rate of the ARH system.
– *Number of movements* Each time that acceleration is approximately zero (with a tolerance threshold) this counter increases in one its value. Therefore, a measure of smoothness is provided.

All metrics, with *total time* exception, were recorded for each surgical tool separately. Furthermore, all subjects were informed about the training protocol and the steps of the laparoscopic suturing procedure. In order to obtain a standardized study, one research assistant supervised the experiments and assured the fulfillment of the task.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics software (version 19.0 for Windows). Data are expressed in terms of mean $\pm$ standard deviation. All numeric variables were considered nonparametric and ordered. Therefore, data from the three independent groups are compared with the Jonckheere–Terpstra test [24]. Differences were considered significant at $P \leq 0.05$.

Results

Tables 1 to 4 show the results of the Jonckheere–Terpstra test for the analyzed groups (novices, intermediates and experts). All metrics were obtained for each subtask. Table 1 shows the first subtask (*needle puncture*) results, while the second subtask results (*first knot*) are shown in Table 2. Finally, the third and fourth subtasks (*second* and *third knot*) are shown in Tables 3 and 4, respectively.

At least one of the metrics of each subtask presents significant differences. The highest number of significant metrics is obtained in the *needle puncture* ,and the *first knot* subtask and the *second knot* subtask obtained no significant metric. Tables 5, 6 and 7 show the pairwise comparison results.

As previously described in the methodology, metrics that are evaluated in all subtasks are *total time*, *total path length*, *partial path length, average speed* and *number of movements*. All of them, except *total time*, are applied to the right and left surgical tool. Most of them give a better punctuation to executions accomplished by experts than to the ones accomplished by novices, although not always the same metric presents significant differences for different subtasks. *Total time* and *total path length* metrics obtain lower values (better punctuation) in all subtasks for experts than intermediates and novices, with exception of second knot subtask where experts spent more time and more total path than intermediates. *Partial path length* metric shows higher values for intermediate surgeons in almost all subtasks. *Average speed* presents higher values for intermediate surgeons with more differences in the right tool than in the left one. *Number of movements* show higher values for nonexperienced surgeons in all subtasks.

Figures 1, 2, 3, 4 and 5 show values of measured metrics for both instruments per subtask and divided by expertise groups. Horizontal bands indicate medians, boxes indicate 25 and 75th percentiles, and whisker lines indicate highest and lowest values. *Total time* shows significant differences in subtasks 1, 2 and 4; *total path length* in subtasks 1, 2 for right and left tools, but in subtask 4 only for right tool and *number of movements* in subtasks 1, 2 for both tools and subtask 4 only for right tool.

Discussion

Laparoscopic suturing procedure is a complex task that has been usually used to assess surgical skills after learning process [11,15,17,19,21]. However, as far as we know there are not many studies that decompose the suture into subtasks, and these studies do not obtain significant differences among groups [25,26]. Although surgical skills assessment has been performed subjectively in the past [27], currently some objective and automated methods have been developed [14] to improve assessment and define a training curricula [21,28].

One of these methods, the ARH system [20], attaches an electromagnetic sensor to the handle of surgical tool to obtain position (x, y, z) and orientation (elevation, azimuth and roll)

Table 1 Measured metrics during the first subtask (needle puncture) of the laparoscopic suturing

Used metrics	Novice (Mean ± SD)	Intermediate (Mean ± SD)	Experienced (Mean ± SD)	*P*-value[a]
Total time (s)	108.07 ± 6.93	57.57 ± 20.29	30.07 ± 13.37	0.001*
Left total path (cm)	203.06 ± 16.79	116.87 ± 41.36	55.54 ± 23.47	0.001*
Right total path (cm)	194.97 ± 24.57	126.35 ± 53.23	47.48 ± 17.98	0.001*
Left partial path (cm)	0.13 ± 0.02	0.14 ± 0.03	0.12 ± 0.02	0.883
Right partial path (cm)	0.12 ± 0.01	0.14 ± 0.04	0.11 ± 0.03	0.659
Left average speed (cm/s)	1.94 ± 0.26	2.11 ± 0.42	1.92 ± 0.33	0.659
Right average speed (cm/s)	1.85 ± 0.13	2.24 ± 0.67	1.69 ± 0.39	0.659
Left movements (#)	176.50 ± 4.04	87.25 ± 33.15	42.50 ± 15.84	0.001*
Right movements (#)	175.00 ± 10.39	81.75 ± 20.90	53.50 ± 27.00	0.002*

[a] Significance is calculated with the Jonckheere–Terpstra test
* Significant differences when $P < 0.05$

Table 2 Measured metrics during the first knot subtask (with double loop) of the laparoscopic suturing

Used metrics	Novice (Mean ± SD)	Intermediate (Mean ± SD)	Experienced (Mean ± SD)	*P*-value[a]
Total time (s)	85.00 ± 5.77	49.00 ± 10.39	37.50 ± 7.19	0.002*
Left total path (cm)	169.02 ± 26.26	136.92 ± 49.89	82.16 ± 22.61	0.008*
Right total path (cm)	154.54 ± 43.65	127.73 ± 8.62	77.87 ± 28.02	0.019*
Left partial path (cm)	0.13 ± 0.01	0.18 ± 0.03	0.14 ± 0.02	0.304
Right partial path (cm)	0.12 ± 0.03	0.18 ± 0.02	0.14 ± 0.02	0.557
Left average speed (cm/s)	2.04 ± 0.20	2.87 ± 0.54	2.24 ± 0.26	0.304
Right average speed (cm/s)	1.85 ± 0.42	2.77 ± 0.34	2.10 ± 0.37	0.659
Left movements (#)	105.50 ± 1.73	50.75 ± 12.09	40.75 ± 4.92	0.003*
Right movements (#)	125.50 ± 10.97	54.00 ± 22.55	53.50 ± 7.23	0.019*

[a] Significance is calculated with the Jonckheere–Terpstra test
* Significant differences when $P < 0.05$

Table 3 Measured metrics during the third subtask (second knot with simple loop and inverse direction)

Used metrics	Novice (Mean ± SD)	Intermediate (Mean ± SD)	Experienced (Mean ± SD)	*P*-value[a]
Total time (s)	31.00 ± 5.77	18.50 ± 5.26	20.50 ± 6.40	0.066
Left total path (cm)	81.17 ± 14.10	40.33 ± 15.90	48.58 ± 10.72	0.056
Right total path (cm)	59.37 ± 6.52	45.53 ± 13.10	51.38 ± 38.06	0.186
Left partial path (cm)	0.18 ± 0.06	0.15 ± 0.06	0.16 ± 0.03	1.000
Right partial path (cm)	0.13 ± 0.04	0.16 ± 0.01	0.15 ± 0.08	0.769
Left average speed (cm/s)	2.83 ± 1.01	2.30 ± 0.89	2.50 ± 0.39	1.000
Right average speed (cm/s)	2.06 ± 0.61	2.56 ± 0.12	2.38 ± 1.19	1.000
Left movements (#)	34.00 ± 8.80	20.75 ± 6.95	26.50 ± 14.64	0.300
Right movements (#)	38.00 ± 13.86	15.75 ± 5.12	25.25 ± 9.54	0.240

[a] Significance is calculated with the Jonckheere–Terpstra test

of the tooltip. The ARH assembly and calibration are easy and quick, so it could be used for real procedures at the operating room in the future when the error system was reduced [20]. There are other groups that solve these errors locating the sensor into the tooltip, but they only can use the tracking system with assembled tools [18,19].

On the other hand, the hand-motion analysis (HMA) has been used in many studies [15,16], but the TMA could enhance the results of motion-tracking in laparoscopic procedures. From our point of view, tracking directly the tooltip movements of the surgical instruments allows determining more accurately and precisely the trajectory of the instrumental within the surgical field than analyzing the hand movements.

The objective of this paper is to perform an in-depth analysis of the laparoscopic suturing task, determine which one of their subtasks is more relevant to assess surgical skills and demonstrate the usefulness of TMA as validation and certification tool.

Results show that the best subtasks to assess surgical skills are the first (execution of the *needle puncture*) and the second one (execution of the *first knot*). In these subtasks, five of

Table 4 Measured metrics during the fourth subtask (third simple knot with inverse direction to the second one)

Used metrics	Novice (Mean ± SD)	Intermediate (Mean ± SD)	Experienced (Mean ± SD)	*P*-value[a]
Total time (s)	28.47 ± 4.54	17.35 ± 4.26	15.27 ± 4.40	0.005*
Left total path (cm)	56.80 ± 13.97	52.60 ± 26.69	41.40 ± 13.22	0.186
Right total path (cm)	57.54 ± 11.45	45.85 ± 15.40	40.60 ± 4.18	0.019*
Left partial path (cm)	0.14 ± 0.05	0.20 ± 0.08	0.19 ± 0.07	0.304
Right partial path (cm)	0.14 ± 0.05	0.17 ± 0.02	0.19 ± 0.05	0.304
Left average speed (cm/s)	2.15 ± 0.84	3.10 ± 1.27	2.86 ± 1.01	0.304
Right average speed (cm/s)	2.18 ± 0.76	2.70 ± 0.38	2.87 ± 0.70	0.378
Left movements (#)	37.50 ± 5.20	18.75 ± 6.70	24.00 ± 12.99	0.089
Right movements (#)	38.00 ± 3.46	17.50 ± 5.32	13.75 ± 7.89	0.006*

[a] Significance is calculated with the Jonckheere–Terpstra test
* Significant differences when $P < 0.05$

Table 5 Pairwise multiple comparison of first subtask between three groups for significant metrics only

Used metrics	Exp–Inter (*P*-value[a])	Exp–Nov (*P*-value[a])	Inter–Nov (*P*-value[a])
Total time (s)	0.125	0.029*	0.029*
Left total path (cm)	0.125	0.029*	0.029*
Right total path (cm)	0.125	0.029*	0.119
Left movements (#)	0.065	0.029*	0.029*
Right movements (#)	0.223	0.029*	0.029*

[a] Significance is calculated with the Jonckheere–Terpstra test
* Significant differences when $P < 0.05$

Table 6 Pairwise multiple comparison of second subtask between three groups for significant metrics only

Used metrics	Exp–Inter (*P*-value[a])	Exp–Nov (*P*-value[a])	Inter–Nov (*P*-value[a])
Total time (s)	0.162	0.029*	0.028*
Left total path (cm)	0.125	0.029*	0.364
Right total path (cm)	0.031*	0.029*	1.000
Left movements (#)	0.368	0.028*	0.029*
Right movements (#)	1.000	0.029*	0.029*

[a] Significance is calculated with the Jonckheere–Terpstra test
* Significant differences when $P < 0.05$

Table 7 Pairwise multiple comparison of fourth subtask between three groups for significant metrics only

Used metrics	Exp–Inter (*P*-value[a])	Exp–Nov (*P*-value[a])	Inter–Nov (*P*-value[a])
Total time (s)	0.580	0.029*	0.029*
Right total path (cm)	0.372	0.029*	0.364
Right movements (#)	0.702	0.029*	0.029*

[a] Significance is calculated with the Jonckheere–Terpstra test
* Significant differences when $P < 0.05$

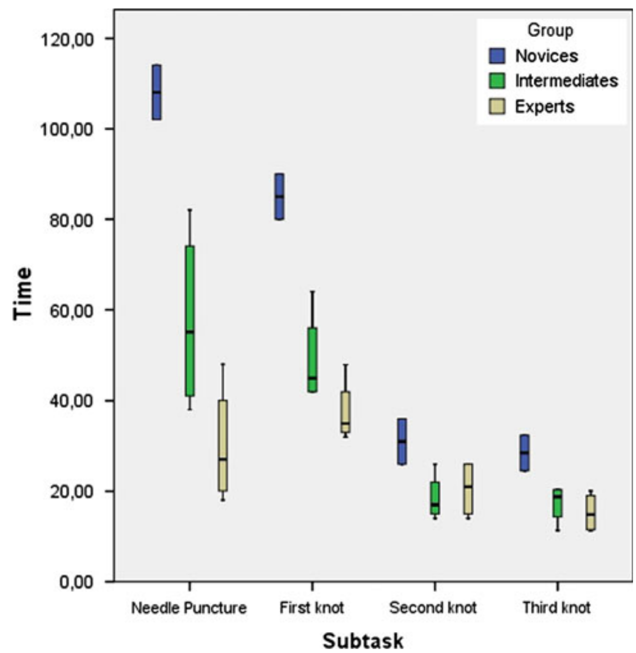

Fig. 1 Comparison of total time (s) to accomplish each subtask by each analyzed group

the nine used metrics obtain significant difference between the three groups (novice, intermediates and experts): *total time, total path* and *number of movements*. Nevertheless, the fourth subtask (the *third knot*) can only distinguish between three levels of surgical experience in three of the nine metrics. Finally, subtasks 3 cannot obtain significant differences.

The pairwise comparison shows significant differences between experienced and novice groups in all metrics with significance. The subtask 1 shows difference between intermediates and novices too. However, only the subtasks 2 can differ experiences from intermediate.

In the first subtask (*needle puncture*), *total time* shows the highest values of the whole study coinciding with Chung and Sackier [29] that conclude that the needle position is the most time-consuming maneuver. Moreover, *number of movements* and *total path length* are the highest for novices too. Therefore, the most difficult subtask could be the *needle puncture* according to Chung and Sackier [29].

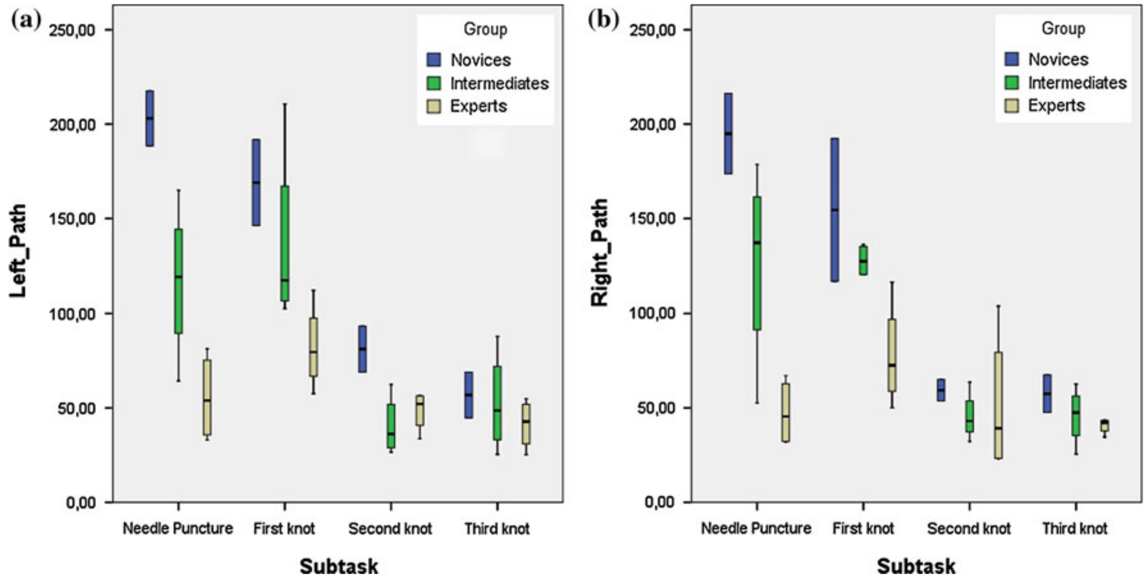

Fig. 2 Comparison of total path (cm) for each subtask by each analyzed group for the **a** *right* instrument and **b** *left* one

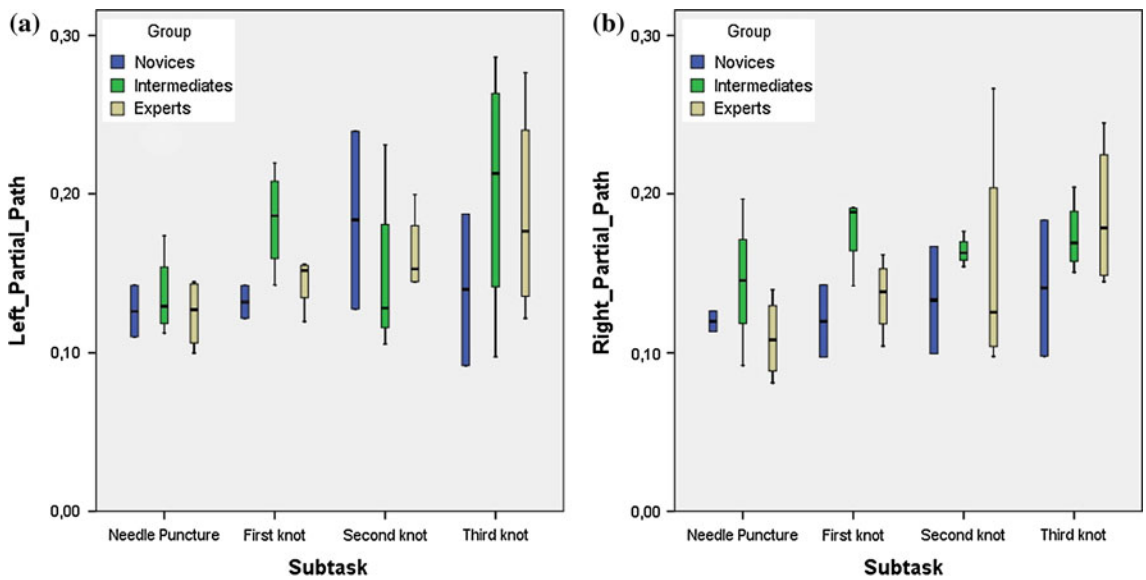

Fig. 3 Comparison of partial path (cm) to accomplish each subtask by each analyzed group for the **a** *right* instrument and **b** *left* one

In the second subtask (*first knot*), novices obtain higher values for *time, total path length* and *number of movements* than intermediates, while experts obtain the lowest values. However, *partial path length* and *average speed* show higher values for intermediates than experts. Although experienced surgeons usually move tools more quickly and accurately than novices, these results could indicate a self-confident of intermediate surgeons that make them to move tools more quickly than needed. As shown by Yamaguchi et al. [19], significant differences were obtained for *total time* and *right average speed*, but our work can significantly differ in*total path length* (*right and left*) and *numbers of movements* (*right and left*) too. They used two groups (experts and novices), while we have used three groups (experts, intermediates and novices).

In the third and fourth subtasks (*second and third knot*), experts present higher *number of movements* than intermediates. Therefore, additional quality control tests must be performed in future works as suggested by Moorthy et al. [30], because the analyzed videos can not explain these values. Maybe, these movements performed by experts are needed to make a safer knot, but we can not assure it without additional experiments.

Recently, Chmarra et al. [31] has shown that expert surgeons do not minimize path length in some surgical tasks. However, our study shows different results for laparoscopic

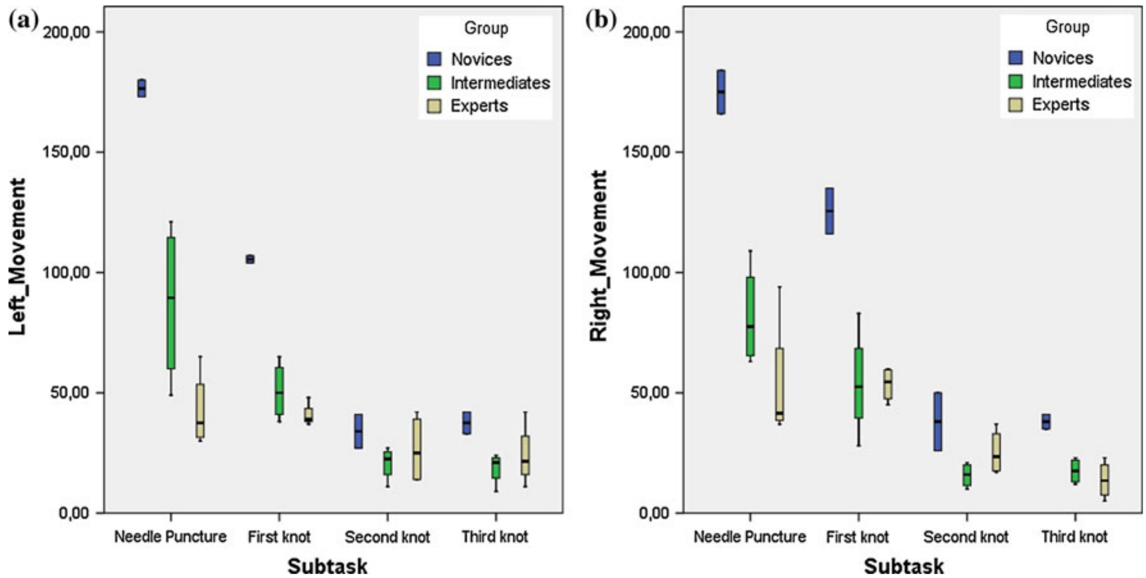

Fig. 4 Comparison of number of movements (#) to accomplish each subtask by each analyzed group for the **a** *right* instrument and **b** *left* one

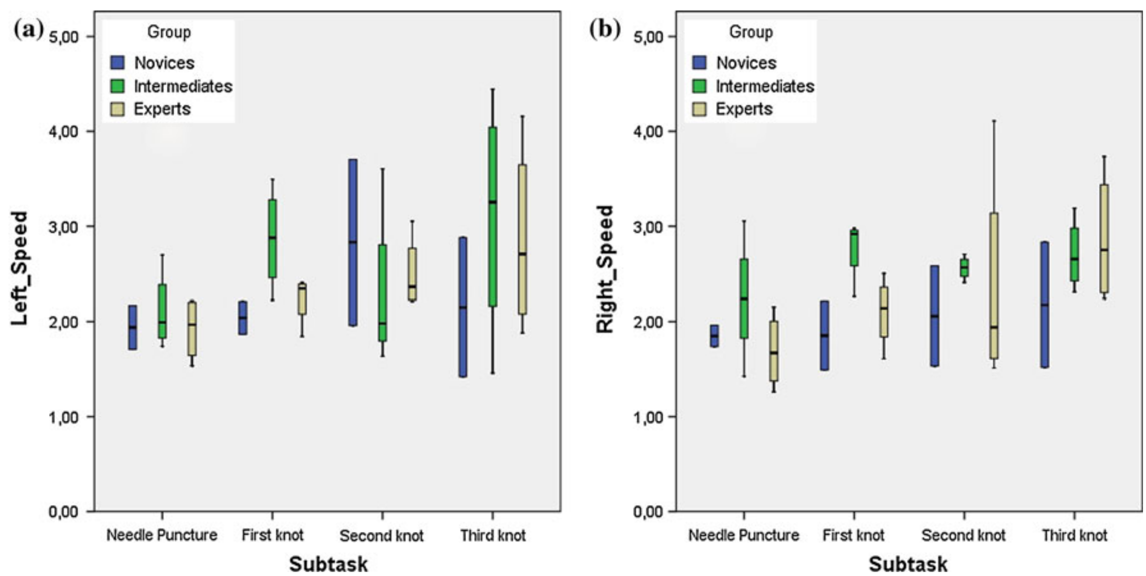

Fig. 5 Comparison of mean speed (cm/s) while accomplishing each subtask by each analyzed group for the **a** *right* instrument and **b** *left* one

suturing task. Three of four analyzed subtasks (1, 2 and 4) present lower *total path length* for experts than intermediates and these ones show lower values than novices too. In the subtasks 1 and 2, significant differences are found between the three groups. On the other hand, subtask 3 shows higher *path length* and *total time* for experts than intermediates. These results suggest that a "surgical pattern" must be calculated with experienced surgeons performances [32] for each task or subtask before any objective metric can be used to assess surgical skills. This "surgical pattern" will define a range of optimum values for each objective metrics.

Our study contributes to know in-depth the laparoscopic suturing task. Before transferring the training knowledge and skills to the operating room (predictive validity) [33], we need to understand the importance and difficulty of all subtasks implied on the learning process. This knowledge could help to develop the training curricula [28] and can be used to increase the training feedback of the most relevant surgical tasks and subtasks [15,30]. In order to build a modern surgical training model that would be useful, it is needed to adapt the task difficulty to the surgeons' needs as suggested by Elneel et al. [34]. Furthermore, according to Allen et al. [32], different level of experience can not be distinguished with simple training tasks, because novices become experts quickly in some “too simple” tasks.

Future works with the TMA must be focused on automating the decomposition of surgical tasks using the ARH system and a VIdeo-based Laparoscopic Assessment (VIDLA) software [23]. Besides, additional metrics, such as know tightness, errors or dwell time, could be added to improve the obtained results and state a more complete link between demonstrated execution of individual elements of the tasks and better performance.

In conclusion, decomposition of laparoscopic suturing task has contributed to the understanding of the most relevant subtasks for training purpose. Therefore, these subtasks are*needle puncture* and *first knot*. Furthermore, the TMA has demonstrated its usefulness as an objective assessment tool and its versatility as a future certification tool of surgical skills.

Acknowledgments This study was partially supported by “Consejería de Economía, Comercio e Innovación, Junta de Extremadura” and the European Social Fund.

Conflict of interest None.

References

1. Buunen M, Gholghesaei M, Veldkamp R, Meijer DW, Bonjer HJ, Bouvy ND (2004) Stress response to laparoscopic surgery—a review. Surg Endosc 18(7):1022–1028
2. Beldi G, Ipaktchi R, Wagner M, Gloor B, Candinas D (2006) Laparoscopic ventral hernia repair is safe and cost effective. Surg Endosc 20(1):92–95
3. Delaney CP, Chang E, Senagore AJ, Broder M (2008) Clinical outcomes and resource utilization associated with laparoscopic and open colectomy using a large national database. Ann Surg 247(5):819–824
4. Usón J, Sánchez FM, Pascual S, Climent S (2007) In: Usón J (ed) Formación en Cirugía Laparoscópica Paso a Paso, 3rd edn. Minimally Invasive Surgery Centre, Cáceres
5. Fried GM (2008) FLS assessment of competency using simulated laparoscopic task. J Gastrointest Surg 12(2):210–212
6. Schout BM, Hendrikx JM, Scheele F, Bemelmans BLH, Scherpbier JJ (2010) Validation and implementation of surgical simulators: a critical review of present, past, and future. Surg Endosc 24(3):536–546
7. Dhariwal AK, Prabhu RY, Dalvi AN, Supe AN (2007) Effectiveness of box trainers in laparoscopic training. J Minim Access Surg 3(2):57–63
8. Lamata P, Gómez E, Sánchez-Margallo F, López Ó, Monserrat C, García V, Alberola C, Rodríguez Florido M, Ruiz J, Usón J (2007) Sinergia laparoscopic virtual reality simulador: didactic design and technical development. Comput Methods Programs Biomed 85(3):273–283
9. Sánchez-Margallo JA, Sánchez-Margallo FM, Pagador JB, Gómez EJ, Sánchez-González P, Usón J, Moreno J (2011) Video-based assistance system for training in minimally invasive surgery. Minim Invasive Ther Allied Technol 20(4):197–205
10. Munz Y, Kumar BD, Moorthy K, Bann S, Darzi A (2004) Laparoscopic virtual reality and box trainers. Is one superior to the other? Surg Endosc 18:485–494
11. Botden SM, Jakimowicz JJ (2009) What is going on in augmented reality simulation in laparoscopic surgery? Surg Endosc 23(8):1693–1700
12. Solis J, Oshima N, Ishii H et al (2008) Towards understanding the suture/ligature skills during the training process using WKS-2RII. Int J Comput Assist Radiol Surg 3(3–4):231–239
13. Pagador JB, Uson J, Sánchez MA, Moyano JL, Moreno J, Bustos P, Mateos J, Sánchez-Margallo FM (2011) Electronic device for endosurgical skills training (EDEST): study of reliability. Int J Comput Assist Radiol Surg 6(3):367–374
14. Reiley CE, Lin HC, Yuh DD, Hager GD (2011) Review of methods for objective surgical skill evaluation. Surg Endosc 25(2):356–366
15. Xeroulis G, Dubrowski A, Leslie K (2009) Simulation in laparoscopic surgery: a concurrent validity study for FLS. Surg Endosc 23(1):161–165
16. Datta V, Bann S, Mandalia M, Darzi A (2006) The surgical efficiency score: a feasible, reliable, and valid method of skills assessment. Am J Surg 192(3):372–378
17. Gunther S, Rosen J, Hannaford B, Sinanan M (2007) The red DRAGON: a multi-modality system for simulation and training in minimally invasive surgery. Stud Health Technol Inform 125:149–154
18. Feng C, Haniffa H, Rozenblit J, Hamilton A, Salkini M (2006) Surgical training and performance assessment using a motion tracking system. Proceedings of European modeling and simulation symposium (EMSS), pp 647–652
19. Yamaguchi S, Yoshida D, Kenmotsu H, Yasunaga T, Konishi K, Ieiri S, Nakashima H, Tanoue K, Hashizume M (2011) Objective assessment of laparoscopic suturing skills using a motion-tracking system. Surg Endosc 25(3):771–775
20. Pagador JB, Sánchez LF, Sánchez JA, Bustos P, Moreno J, Sánchez-Margallo FM (2011) Augmented reality haptic (ARH): an approach of electromagnetic tracking in minimally invasive surgery. Int J Comput Assist Radiol Surg 6(2):257–263
21. Munz Y, Almoudaris AM, Moorthy K et al (2007) Curriculum-based solo virtual reality training for laparoscopic intracorporeal knot tying: objective assessment of the transfer of skill from virtual reality to reality. Am J Surg 193(6):774–783
22. Dosis A, Aggarwal R, Bello F et al (2005) Synchronized video and motion analysis for the assessment of procedures in the operating theater. Arch Surg 140(3):293–299
23. Pagador JB, Sánchez-Margallo FM, Sánchez-Peralta L, Sánchez-Margallo JA, Enciso S, Moreno J (2010) Objective assessment of basic laparoscopic skills using automatic video-based technique. Minim Invasive Ther Allied Technol 19(Suppl1):55
24. Sheskin D (2007) Handbook of parametric and nonparametric statistical procedures. Chapman & Hall/CRC, London
25. Reiley CE, Hager GD (2009) Task versus subtask surgical skill evaluation of robotic minimally invasive surgery. Med Image Comput Comput-Assist Interv: MICCAI 12(Pt 1):435–442
26. Jayaraman S, Trejos AL, Naish MD, Lyle A, Patel RV, Schlachta CM (2011) Toward construct validity for a novel sensorized instrument-based minimally invasive surgery simulation system. Surg Endosc 25(5):1439–1445
27. Darzi a, Smith S, Taffinder N (1999) Assessing operative skill. Needs to become more objective. BMJ 318(7188):887–888
28. McClusky Da, Smith CD (2008) Design and development of a surgical skills simulation curriculum. World J Surg 32(2):171–181
29. Chung J, Sackier J (1998) A method of objectively evaluating improvements in laparoscopic skills. Surg Endosc 12:1111–1116
30. Moorthy K, Munz Y, Dosis A et al (2004) Bimodal assessment of laparoscopic suturing skills: construct and concurrent validity. Surg Endosc 18(11):1608–1612

31. Chmarra MK, Jansen FW, Grimbergen Ca, Dankelman J (2008) Retracting and seeking movements during laparoscopic goal-oriented movements. Is the shortest path length optimal? Surg Endosc 22(4):943–949
32. Allen B, Nistor V, Dutson E et al (2010) Support vector machines improve the accuracy of evaluation for the performance of laparoscopic training tasks. Surg Endosc 24(1):170–178
33. Seymour NE (2008) VR to OR: a review of the evidence that virtual reality simulation improves operating room performance. World J Surg 32(2):182–188
34. Elneel FH, Carter F, Tang B, Cuschieri A (2008) Extent of innate dexterity and ambidexterity across handedness and gender: implications for training in laparoscopic surgery. Surg Endosc 22:31–37