Analysis of Surgeons' Muscle Activity During the Use of a Handheld Robotic Instrument in Laparoendoscopic Single-Site Surgery

Francisco M. Sánchez-Margallo and Juan A. Sánchez-Margallo

Abstract The objective of this study is to assess the surgeon's performance and ergonomics during the use of a robotic-driven handheld laparoscopic instrument in intracorporeal suturing tasks as well as in digestive and urological laparoscopic procedures performed through single-site surgery, and comparing it with the use of conventional instruments. Seven right-handed experienced surgeons took part in this study. Four surgeons performed nine urethrovesical anastomoses on an ex vivo porcine model and three surgeons a partial nephrectomy and a sigmoidectomy on an in vivo animal model. Surgeons used both conventional laparoscopic instruments and the robotic instrument. Execution times, leakage pressure for the anastomosis, surgical complications and surgeons' muscle activity were measured. Similar results in surgical performance and ergonomics were obtained using conventional laparoscopic instruments and the robotic instrument. Muscle activity of the biceps was significantly higher using the robotic instrument during both surgical procedures.

Keywords Laparoendoscopic single-site surgery · Handheld robotic instrument · Ergonomics · Muscle activity

1 Introduction

Laparoscopic surgery has experienced rapid development in recent years, providing multiple advantages for the patient such as the reduction in postoperative pain, tissue trauma and infection rate, better aesthetic results, and shortened recovery period [1–3]. In this sense, laparoendoscopic single-site surgery (LESS) is being

F.M. Sánchez-Margallo (✉)
Jesús Usón Minimally Invasive Surgical Centre, Cáceres, Spain
e-mail: msanchez@ccmijesususon.com

J.A. Sánchez-Margallo
Department of Computer Systems and Telematics Engineering,
University of Extremadura, Badajoz, Spain
e-mail: jasmargallo@unex.es

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consolidated as a real alternative to conventional laparoscopic surgery which further reduces incision related complications and leads to better cosmetics results. Numerous studies sustaining its feasibility, advantage in pain and recovery time with respect to conventional surgery, and therapeutic safety [4–6]. In this surgical approach, a multichannel surgical port is used to have access to the abdominal cavity of the patient where articulated or prebent instruments are introduced.

LESS surgery as a new evolving surgical technique still represents a challenge for surgeons, which requires surgical expertise [7]. This surgical approach presents some technical difficulties such as the closer proximity of instruments and loss of instruments triangulation, leading to clashing and crossing of the instruments both inside and outside the patient [8]. These technical constraints lead to a restriction of movements for the surgical instruments, which makes surgeons to adopt static postures of head and torso and awkward body postures for long periods of time. This could lead to deficient ergonomic conditions during surgery [9, 10], increasing the possibilities of muscle fatigue and musculoskeletal injuries [11–13].

In order to overcome some of these technical difficulties in LESS, training is necessary to become proficient in this new surgical approach as well as using its specifically designed instruments. In addition, new handheld robotic systems have been developed for laparoscopic surgery and single-site surgery [14–16]. They provide precision-driven and articulating instrument tips, which increase the triangulation, and therefore improve the performance of some surgical maneuvers. One example of these systems is Kymerax™ (Terumo Europe NV, Leuven, Belgium), which offers interchangeable articulating instruments controlled by its handle interface.

Apart from dealing with some of the technical limitations of LESS, the use of these handheld robotic systems could improve the ergonomic conditions as compared to conventional instruments, reducing the risk of musculoskeletal injuries, since they do not require adopting forced postures to perform certain maneuvers within the abdominal cavity. The objective of this study is to assess the surgeon's performance and muscle activity during the use of a robotic-driven, handheld articulating laparoscopic instrument in intracorporeal suturing tasks as well as in digestive and urological LESS procedures, and comparing it with the use of conventional instruments.

2 Materials and Methods

2.1 Participants

Seven right-handed surgeons took part in this study. Four experienced surgeons in laparoscopy (>100 laparoscopic procedures) and with different experience in LESS participated in the study with the training environment. Three experienced surgeons in laparoscopy and LESS (>20 LESS procedures) and with experience using the robotic instrument participated in the study with the experimental animal model. Participants used both conventional laparoscopic instruments (Conv) and the handheld robotic instrument (Rob). The type of instrument (conventional or robotic) to start the task or surgical procedure was randomly assigned to each surgeon. All trials were performed at our centre's experimental surgical theatres. Participants gave informed consent and voluntarily agreed to participate in the studies.

2.2 Handheld Robotic Instrument

The Kymerax™ system (Terumo Europe NV) is a handheld laparoscopic instrument with articulating and interchangeable instruments (scissors, dissector, needle holder and L-hook), which are driven by robotic technology. Surgeons control the movements of the instrument tip through the manipulation of the handle interface. The shaft diameter of its instruments is 8.8 mm.

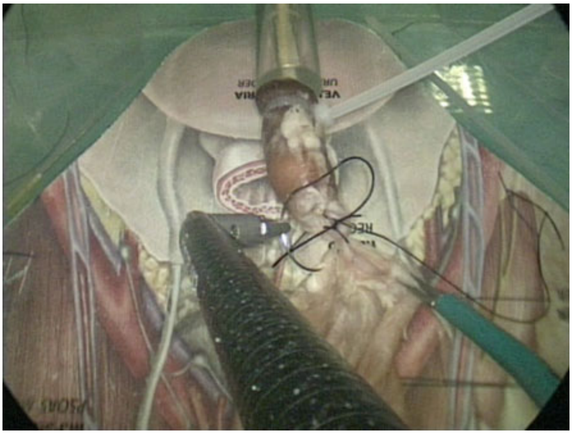
2.3 Training Environment

The training environment consisted of a validated laparoscopic simulator (SIMULAP®; JUMISC, Cáceres, Spain), with a 10-mm, 30° rigid laparoscope (Karl Storz GmbH & Co. KG, Tuttlingen, Germany) as vision system, and the GelPOINT® Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA) as surgical access port. The laparoscope was fixed to prevent movements and changes in the instruments. Surgeons hold an angled inline laparoscopic dissector (Epix®; Applied Medical) on the left hand. On the right hand, they hold a straight laparoscopic needle holder (Karl Storz GmbH & Co. KG) or the robotic instrument in its needle holder configuration for the conventional and robotic groups, respectively (Fig. 1). Participants were asked to performed nine urethrovesical anastomoses on an ex vivo porcine model in a period of two months using both types of laparoscopic instruments (Fig. 2). The anastomosis was performed on an ex vivo porcine bladder using 8 simple interrupted sutures.

During the first (T1) and last (T9) repetitions, execution time, leakage pressure and surgeons' muscular activity were assessed. The leakage test was performed at the end of the task to test the integrity of the anastomosis. This test consisted of introducing a silicone tube connected to an insufflator (Karl Storz GmbH & Co. KG) through the end of the bladder. While the bladder was immersed in water, the pressure at which air leaked from the anastomosis was recorded. The maximum pressure was set at 30 mmHg.

Fig. 1 Setup for the study in the training environment using (*left*) a conventional laparoscopic needle holder and (*right*) the robotic instrument

Fig. 2 Use of the robotic instrument during the urethrovesical anastomosis



2.4 Experimental Animal Model

Participants performed a partial nephrectomy and a sigmoidectomy on an experimental porcine model through LESS approach. For the partial nephrectomy, an artificial pseudotumor was previously created on the upper renal pole of the left kidney. A mixture of alginate and saline was percutaneously injected to reproduce the tumor. This study was reviewed and approved by the Institutional Review Board of the Jesús Usón Minimally Invasive Surgery Centre.

Suturing tasks were analyzed during both surgical procedures. Specifically, measurements were obtained during the hemostasis in the case of partial nephrectomy and during the anastomosis between the descending colon and rectum

Fig. 3 Setup for the study with the animal model. The surgeon is using the robotic instrument with the needle holder end-effector during the surgical procedure. Surface electromyography is used to record the surgeon's muscular activity

in the sigmoidectomy procedure. The GelPOINT® Advanced Access Platform (Applied Medical) was used as surgical access port. In all cases, surgeons hold an articulated laparoscopic dissector (Dissect SILS®; Covidien, Mansfield, MA, USA) on the left hand. On the right hand, they hold a straight laparoscopic needle holder (Karl Storz GmbH & Co. KG) or the robotic instrument with the needle holder end-effector for the conventional and robotic groups, respectively. For each procedure, the surgery time, surgical complications and the surgeon's muscular activity were measure (Fig. 3).

2.5 Surface Electromyography Protocol

For the electromyography (EMG) analysis, we used the MP150 System (Biopac Systems, Inc., Goleta, CA, USA) connected to a laptop (VAIO®; VAIO Corporation, Nagano, Japan) equipped with the AcqKnowledge 3.7 acquisition software (Biopac Systems, Inc.).

EMG signals were obtained from right biceps brachii, right triceps brachii, right forearm flexors and extensors, and right trapezius muscles, through triple-surface electrodes. The electrodes were placed according to the SENIAM recommendations for each muscle [17]. Before its placement, the skin was cleaned with alcohol to eliminate dirt remnants, grease, and dead skin cells that could impair the acquisition of EMG signals. To prevent movement of the electrodes, they were fixed using an elastic band. Cables were also attached to the surgeon's clothes to reduce potential artifacts. The sample rate was established at 1000 Hz.

Once the electrodes were adequately positioned, the measurement of the maximal voluntary contraction (MVC) of each muscle was recorded for amplitude normalization. MVC was recorded separately for each muscle group by asking the subject to perform specific 8-s tractions against a fixed resistance. This was used as a reference to normalize every EMG recording as a percentage of the MVC, which allows for comparison between different subjects.

After the EMG data of each group of muscles was recorded for each activity, the signal was visually inspected and filtered to remove possible artifacts. The root mean square value of the signal was calculated for each muscle, expressing the final results as a percentage of the corresponding MVC.

2.6 Statistical Analysis

For statistical analysis, the Wilcoxon signed rank test was used to compare measurements of both study groups. All statistical analyses were carried out using R version 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria). The results are shown as mean and standard deviation or notched box and whisker plots. For the latter, the boxes whose notches do not overlap their medians are significantly different with 95 % confidence. For all tests, $p < 0.05$ was considered statistically significant.

3 Results

3.1 Training Environment

The average time required to perform an intracorporeal suture during the urethrovesical anastomosis was similar using both instruments during T1 (Conv: 5.652 ± 3.744 min; Rob: 5.909 ± 2.384 min). However, during T9, the average time was significantly less using the conventional needle holder than the robotic instrument (Conv: 3.570 ± 1.334 min; Rob: 4.174 ± 1.356 min; $p = 0.015$). A reduction in the execution time was shown between T1 and T9 for both study groups.

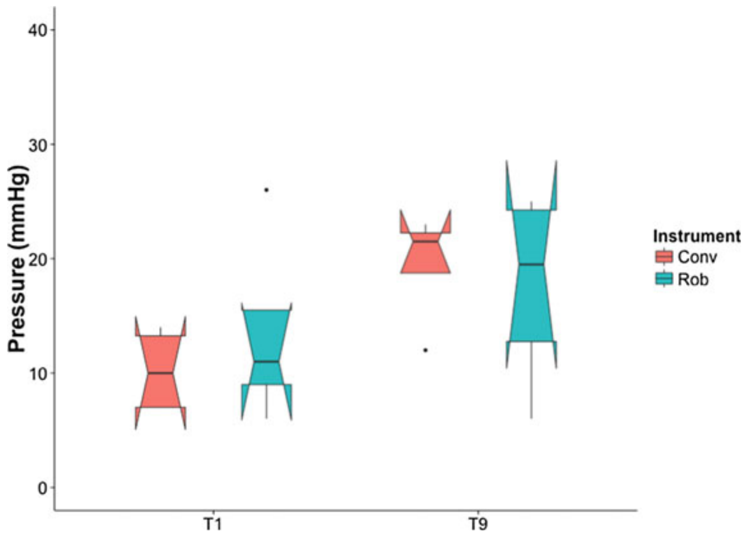


Fig. 4 Results of the leakage test during T1 and T9. The leakage pressure was measured at the end of the urethrovesical anastomosis performed by the conventional laparoscopic needle holder (Conv) and the robotic instrument (Rob)

Muscle activity of the analyzed muscles was similar between the use of both laparoscopic instruments for the urethrovesical anastomosis during T1 and T9 (Fig. 4). Muscle activity of biceps (T1: 22.448 ± 6.845 %MVC; T9: 7.867 ± 1.743 %MVC) and flexor (T1: 31.804 ± 5.630 %MVC; T9: 9.202 ± 6.074 %MVC) muscles decreased significantly from the first (T1) to the last (T9) repetition using the robotic instrument.

The leakage pressure for the anastomosis was similar during T1 and T9 for both groups of laparoscopic instruments (Fig. 5). The pressure supported by the anastomosis performed by the conventional laparoscopic needle holder increased significantly from the first (T1) to the last (T9) repetition.

3.2 *Experimental Animal Model*

All surgical procedures were successfully performed and no complications were registered (Fig. 6). Surgery time of both procedures was similar using the conventional and the robotic laparoscopic instruments.

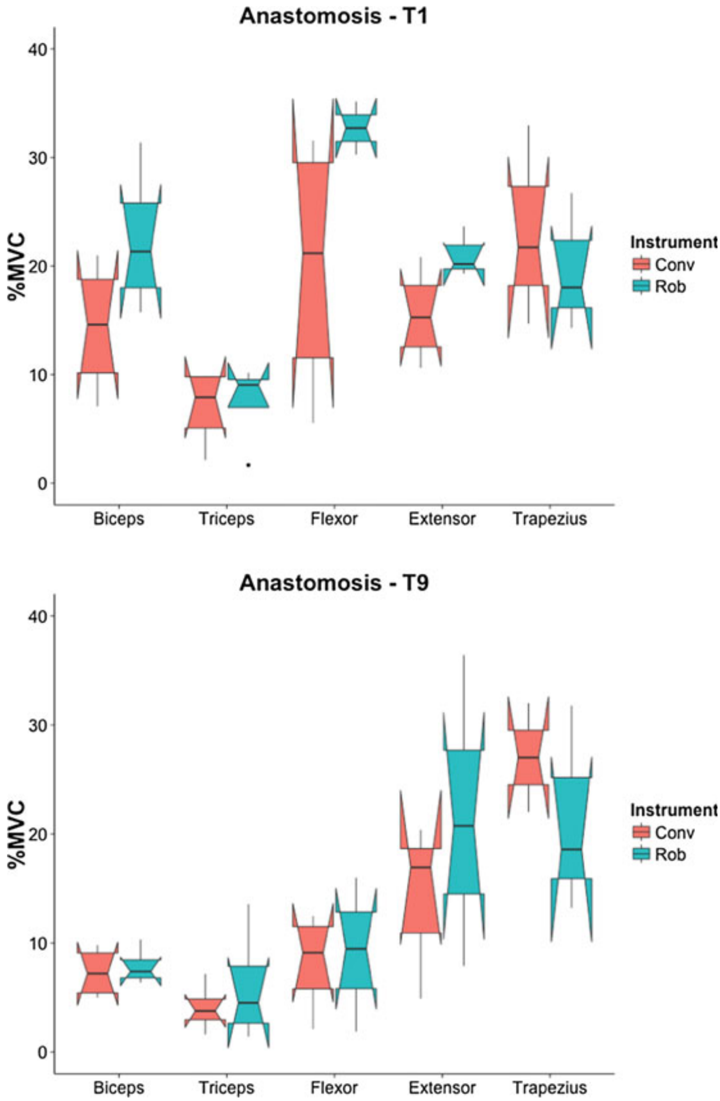


Fig. 5 Muscle activity (%MVC) of each analyzed muscle using conventional instruments (Conv) and the robotic instrument (Rob) during the first (T1) and last (T9) repetitions of the urethrovesical anastomosis task

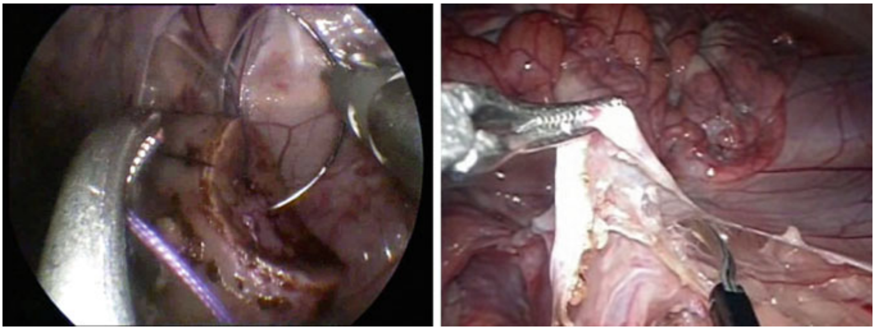


Fig. 6 Surgical procedures on the experimental animal model. *Left* Partial nephrectomy using the robotic instrument and *Right* sigmoidectomy with conventional laparoscopic instruments

Muscle activity of the biceps was significantly higher using the robotic instrument during both partial nephrectomy (Conv: 4.366 ± 2.575 %MVC; Rob: 6.774 ± 0.620 %MVC) and sigmoidectomy (Conv: 2.086 ± 0.306 %MVC; Rob: 6.254 ± 0.705 %MVC) procedures (Fig. 7). No significant differences were observed for the other analyzed muscles.

4 Discussion

LESS surgery is technically challenging for surgeons and its limited range of movements for the surgical instruments inside the abdominal cavity could lead them to adopt awkward postures for long periods of time, with the consequent possible musculoskeletal injuries [9, 11, 12]. Several devices and prototypes with articulating tip have been developed as a possible solution for these limitations [14, 16, 18]. These instruments enable surgeons to achieve movements not usually possible with conventional instruments. In this study we analyzed the performance and ergonomics using the Kymerax™ system (Terumo Europe NV), a robotic-driven handheld instrument with a flexible tip, during suturing tasks in a training environment and during digestive and urologic surgical procedures on an animal model.

Similar results in surgical performance and ergonomics were obtained using conventional laparoscopic instruments and the handheld robotic instrument during the urethrovesical anastomosis in the experimental environment and during the partial nephrectomy and sigmoidectomy procedures on an animal model using a LESS approach.

For the urethrovesical anastomosis in the training environment, there was a remarkable improvement in execution time during the last repetition for both laparoscopic instruments. In this repetition, the execution time using the conventional needle holder was significantly lower than using the robotic instrument, which

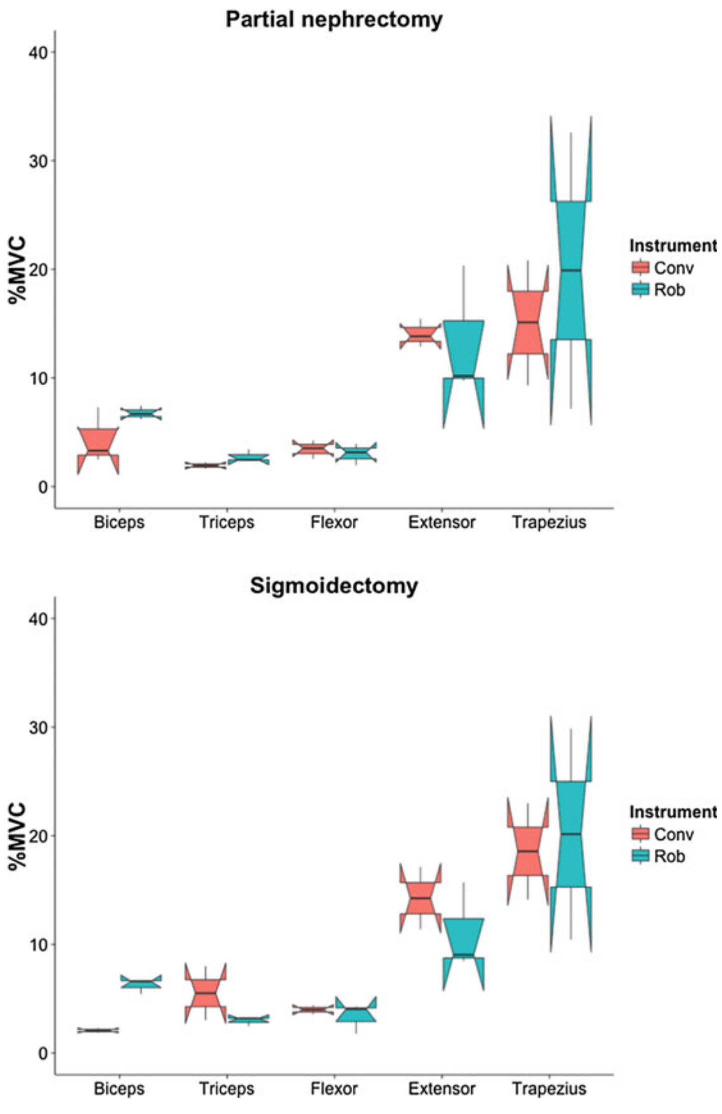


Fig. 7 Muscle activity (%MVC) of each analyzed muscle using conventional instruments (Conv) and the robotic instrument (Rob) during partial nephrectomy and sigmoidectomy procedures

might be due to the previous experience of the surgeons with conventional laparoscopic instruments. In another study with basic suturing tasks, no differences in execution time using conventional or the handheld robotic instrument were found [15]. However, in this study participants only performed three repetitions of each task. A longer training period with the robotic instrument could positively affect the learning curve for this device, improving the performance in intracorporeal suturing.

Muscular activity of both biceps and flexor muscles was reduced from the first to the last repetition during the performance of the urethrovesical anastomosis using the robotic instrument. It seems that training improves the ergonomics of surgeons using the robotic instrument. However, during the surgical procedures, this instrument demanded higher muscular activity for the biceps. This might be because the robotic instrument is bigger and heavier than the conventional laparoscopic instrument, leading to higher workload of the biceps muscle.

As was reported by Pérez-Lanzac et al. [19], the surgeons stated that the use of the robotic instrument reduced the technical difficulty of the urethrovesical anastomosis performed through LESS approach. Participants in the study with the laparoscopic simulator considered that it should be necessary a previous training to be familiarized with the controls on the device.

The use of this robotic instrument has been also proved to be feasible in other laparoscopic procedures such as total laparoscopic hysterectomy and radical prostatectomy [18, 20]. A study with sixty patients who underwent a robot-assisted radical prostatectomy reported no differences between using conventional laparoscopic and robot-assisted procedures with regard to postoperative pain, blood loss and length of recovery [20].

The main limitation of the presented study is the small sample size. Further studies should be done including other handheld robotic laparoscopic instruments to support the results obtained. Understanding how operation conditions, workplace layout and surgical instruments influence surgeons' ergonomic condition could provide inspiration for new instrument designs, as well as more targeted training methods.

In conclusion, results indicated a positive learning curve in performance and ergonomics using the handheld robotic instrument for LESS urethrovesical anastomosis. Besides, results showed that partial nephrectomy and sigmoidectomy procedures performed through LESS approach and using the robotic instrument are feasible and safe. There were no differences in surgery time and surgeon's muscle activity during both surgical procedures, except for the biceps muscle. We consider that a period of adaptation should be required for this new technology.

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