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SURG INNOV published online 5 September 2012

DOI: 10.1177/1553350612456100

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Surgical Innovation
XX(X) 1–8
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Abstract

In single-access surgery, instruments enter the abdominal cavity through only 1 incision, the position of the instruments relative to each other is different compared with that in conventional laparoscopy. Changes in instrument configuration may increase task complexity and therefore affect tissue handling skills. The aim of this study is to determine if a relation exists between instrument configuration and tissue interaction force. A study was performed to investigate the differences in manipulation force between a single-port (SP) and 2-port (TP) instrument configuration in a standard box trainer. A force platform was placed under a tissue manipulation task in a box trainer and used to measure the pulling forces and trial time. A total of 28 medical students with no previous experience in laparoscopic surgery were divided into 2 equal groups. Group 1 trained the task 6 times with the TP configuration and subsequently performed 6 trials with the SP configuration. Group 2 used the configurations in the opposite order. For both groups, the learning curves of the maximum force and task time were compared. Time and maximum pulling forces were significantly different between the 2 instrument configurations. In both groups, the participants used significantly more force in the SP configuration than in the TP configuration. The force data indicate that the increased complexity in instrument handling with straight instruments in a SP configuration increases the tissue manipulation force. Furthermore, the tissue handling skills of novices who mastered the task with the TP configuration decreased after switching to the SP configuration.

Keywords

SILS/single-site surgery, biomedical engineering, surgical education

Introduction

In minimally invasive surgery, instrument motion is limited to translations and rotations at the incision point. In single-access surgery, where all instruments and the laparoscope are inserted through 1 incision, contact between instrument shafts and instrument handles limits the freedom of movement of the surgeon even more. Some studies suggest that those limitations in movements result in longer operation times because of increased complexity.^{1–4} In studies focusing on skills comparison in box trainers, similar results were found.^{5,6} No studies were found that investigated the influence of the single-access surgery technique on tissue handling. However, there are reasons to assume that tissue handling is more difficult in single-access surgery. In standard laparoscopy, a large

work space can be realized by retracting the instruments or by rotating the instruments away from each other. However, as Figure 1 shows, in a single-access surgery configuration, the surgeon is forced to cross the instruments to obtain sufficient distance between instrument tips.

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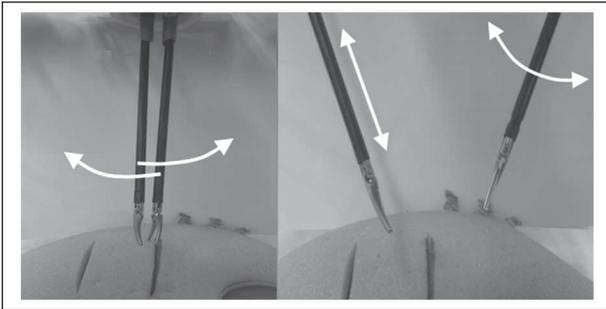


Figure 1. Left: In single-access surgery, instruments must cross to increase the working distance between tips. Right: In standard laparoscopy, instruments can be retracted or rotated around their pivot points to increase the working distance between tips

Continuous surface contact between shafts results in friction during movements, disturbing the tactile feedback at the handles. Distorted tactile feedback could also influence the force control required for safe manipulation of tissue. Figure 2 shows that the risk of continuous shaft contact between the 2 instrument shafts is higher in single-access surgery because of the minimum space between handles.

To prevent instrument handle interaction and to increase the working area in the abdominal cavity, the surgeon can choose either to cross the shafts of the straight instruments or to use special prebent instruments.⁶ However, the increased complexity in handling the instruments is likely to increase the mental task load as well.⁷ Therefore, besides instrument collisions and distorted tactile feedback, an increased mental task load could also influence the tissue handling skills of the surgeon in a negative way.

Study Objectives

The main objective of this study is to investigate the influence of standard 2-port (TP) instrument configuration and single-port (SP) instrument configuration on tissue handling skills. The maximum tissue manipulation force and trial time are recorded during each trial and represent the tissue manipulation skills in this study. The second objective of this study is to determine how novices evaluate the difficulty of both configurations after training and which factors influence this evaluation. In the experiment, we used identical instruments in both configurations to ensure that possible performance differences are only caused by the position of the entry ports of the instruments.

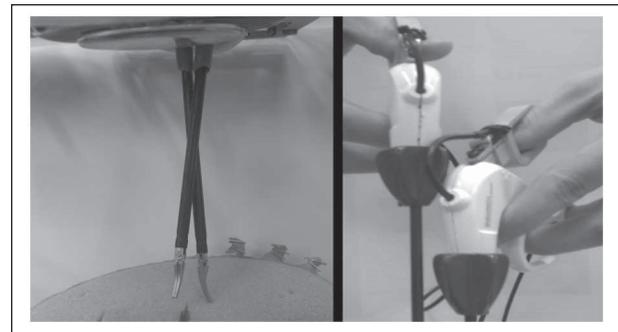


Figure 2. Single-access surgery in box trainer: instrument shafts (left) and handles or hands (right) are likely to collide

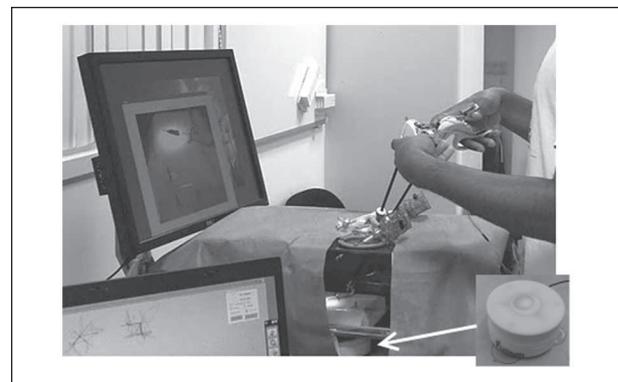


Figure 3. Schematic overview of the training session: instruments are given to all students 5 minutes before the training starts. Group 1 starts to train according to the TP technique. Group 2 starts to train according to the SP. After the sixth trial, the techniques are exchanged for the last 6 trials. Students were randomly assigned to the groups, and those who exceeded a trial time of 15 minutes during the first trial (pretest 1) were excluded from the session. Abbreviations: SP, single port; TP, 2 port.

Materials and Methods

Participants

The total test group consisted of 28 first- and second-year medical students recruited from Leiden University Medical Center without hands-on experience in laparoscopic surgery or training. The participants were randomly assigned to 1 of the 2 experimental groups (Figure 3).

Experimental Setup

A force platform was developed consisting of a force sensor to measure time and force in laparoscopic box trainers ranging from 0 to 10 N in 3 dimensions with an

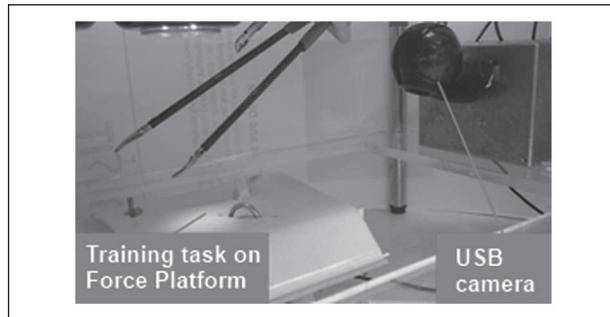


Figure 4. Training setup: a standard box trainer modified for SP and equipped with force platform (below right) to measure all forces exerted on the training task

accuracy of 0.1 N and a measurement frequency of 60 Hz.⁸ A Webcam (Logitech, Webcam C600) was used to capture images of the work space of the instruments. Figure 4 shows the setup built from a modified standard box trainer that is commonly used in laparoscopic training. To allow the use of a SILS port, an extra entry was made between the 2 existing entry points.

A tissue manipulation task that made use of artificial tissue was mounted on top of the force platform. All forces that are exerted with the straight laparoscopic instruments on the artificial tissue are measured with the force platform and stored on a computer. Figure 5 shows how the Webcam, tissue manipulation task, and force platform are fixed inside the modified box trainer.

Battery-powered light sources with 3 white LEDs were placed under the top plate of the box to create a small light beam on the place of interest on the training task. Comparable with real laparoscopic camera systems, the light beam creates a more realistic vision inside the box trainer.

A user interface was built in MATLAB to display the camera image inside a separate screen while data were recorded from the force platform at a rate of 30 Hz. The data were saved in arbitrary units together with a time vector. Because the relation between the force sensor output and the applied forces in newtons is known after calibration, the output is computed in newtons.⁸

Instruments

For both experimental configurations—SP and TP—2 standard laparoscopic forceps were used (Ethicon Endo-Surgery, Johnson & Johnson). To guide the instruments in the SP configuration, a soft-plastic single-incision trocar (SILS trocar, Covidien Surgical, Norwalk, CT) was used. For the TP configuration, two 5-mm trocars (Endopath, Ethicon Johnson & Johnson) were used.

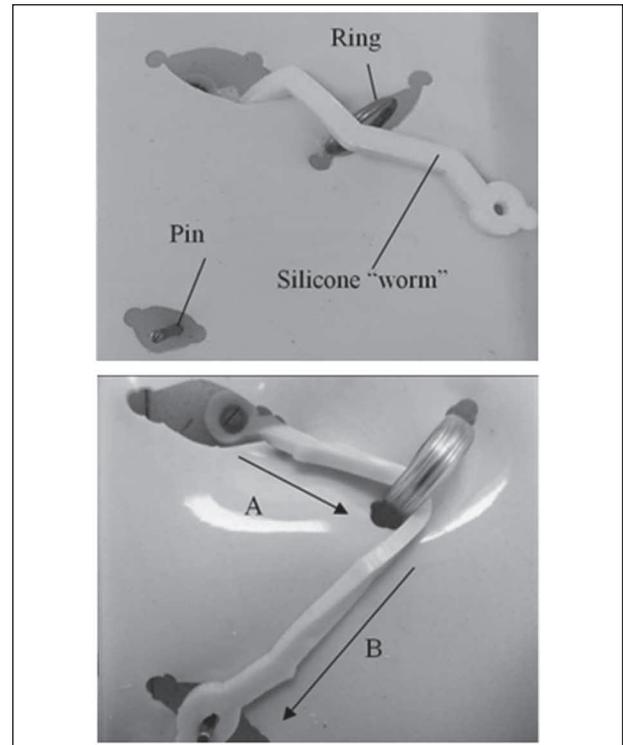


Figure 5. Inside view of modified box trainer: a fixed USB camera with LED lights was used to obtain the video images during training. A custom made silicone training task is fixed on top of the force platform

Training Task

A custom-made silicone training task was fixed on the force platform (Figure 6). This task was based on actions identified in a number of WeBSurg videos about single-access procedures.⁹ The training task involves a worm-like string of silicone that has to be navigated through a small ring (phase A) and precisely hooked on a pin (phase B). During phase A, the loose end of the artificial tissue needs to be carefully positioned inside the laparoscopic gripper before it can be navigated through the ring. Similar actions are found during tissue dissection. In tissue dissection, 1 laparoscopic gripper is used for the positioning of tissue inside the view of the camera. The orientation of the tissue inside the gripper is crucial to achieve a straight cut at the desired location. Part B of the task, precise navigation of tissue under tractive force, can be recognized in surgery during laparoscopic sterilization. In female sterilization, the ovarian tube needs to be positioned perpendicular to the laparoscopic camera and stretched for precise placement of a clip or ring. Compared with stretching the “worm” before placing it over a small

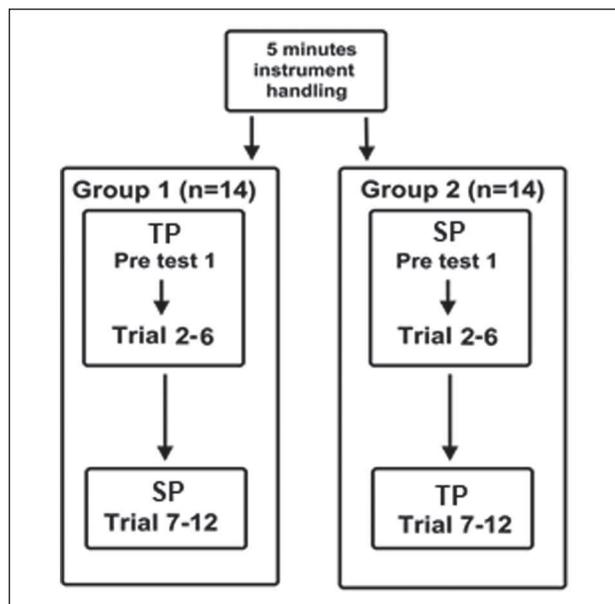


Figure 6. Top: the silicone training task at the beginning of the session. Below: the silicone training task at the end of the session. The head of the “worm” is navigated through the ring (A). After stretching, the head is pushed over a pin (B)

pin in our task, placement of a clip on a stretched ovarian tube requires precise alignment of instruments and tissue. During this 2-handed action, it is essential that the tractive force, generated by 1 instrument, stays low and constant even if the clip is applied by the other instrument.

To mimic blocking of view by organs and connective tissue, the ring and pin are partially hidden under a highly elastic silicone layer. To reach the ring and pin, the silicone layer needs to be pressed downward. To complete the task efficiently, cooperation between both instruments is required at all times. To ensure that the tissue handling complexity of the task represents the surgical actions in SAS sufficiently, 6 experienced surgeons (practicing in Italy or the Netherlands) were asked to try the training task and to give their opinion.

Figure 6 shows the task before and after it was completed. All students were asked to navigate the head of the silicone “worm” through the ring. The task was finished after the tissue was stretched and the end of the tissue was placed with its hole over a pin.

Procedure

In the experiment, each participant was asked to pick up the head of the worm-like tissue and to navigate it through the ring with 1 instrument. As soon as the head of the tissue passed the ring, a mark was given in the software. From here, the participant was asked to stretch the tissue as gently as possible to hook the opening over the pin. All students were told that the artificial material was delicate

and should be handled with care. The tissue handling task was performed 12 times during a single measurement session. Students who exceeded a trial time of 15 minutes at the first attempt were excluded from the study.

To investigate the influence of the skills learned during task performance with the TP configuration on task performance with the SP configuration and vice versa each student was asked to perform 6 trials using 1 technique, followed by 6 trials using the other technique.

In previous experiments, we found that for relatively simple tasks, possible learning effects stabilize after 6 training sessions.⁸⁻¹⁰ Therefore, all participants were asked to train for a minimum of 6 trials before starting the experiment. To get familiar with the handles and functionality of the instruments, students were given the instruments 5 minutes prior to the start of the training session.

After the training session, the students from both groups were asked to rate the 1st, 6th, 7th, and 12th trial of the training session on a scoring list. A mark of “1” meant that the trial was very difficult, and “10” meant that it was very easy. Finally, all students were asked which configuration (eg, TP or SP) they preferred. For the students who preferred the SP configuration over the TP configuration, the difference in tissue handling performance was determined to investigate if their preference was reflected in the tissue handling force and performance time.

Analysis

The forces over time for all 3 directions, F_x , F_y , and F_z , were obtained from the recorded data. The X , Y , and Z components of the force were defined relative to the force platform. Using the square roots of F_x , F_y , and F_z , we calculated the absolute force. The maximum absolute force was considered as the maximum value in the absolute force vector.

The differences in maximum absolute force and task completion time for the 6th and 12th trials were analyzed using a 2-tailed ANOVA test (SPSS, version 16). A P value less than .05 was taken to indicate a significant difference.

Results

To ensure that the complexity of the task represents the surgical actions in single-access surgery sufficiently, 6 experienced surgeons were asked to try the training task and to give their opinion. We found that 5 surgeons judged the task complexity to be comparable to what they experience in actual single-access surgery. However, in actual surgery, 2 of these surgeons make use of bent instruments, and one of them used 1 straight instrument instead of 2 straight instruments; 3 surgeons indicated use of a 30° scope in real practice. On average, it took the 6 surgeons 71 s (standard deviation [SD] = 29 s) to complete the task.

Table 1. Overview of the Scores Given to the First and Last Trials of Each Technique^a

| Student Number (Group 1) | Start | TP Laparoscopy | | SP Laparoscopy | | Preference |
|-----------------------------|-------|----------------|----------------|----------------|----------------|------------|
| | | First Trial | Sixth Trial | Seventh Trial | Twelfth Trial | |
| 1 | SL | 7 | 9 | 2 | 7 | TP |
| 2 | SL | 3 | 8 | 2 | 6 | TP |
| 3 | SL | 7 | 8 | 6 | 7 | TP |
| 4 | SL | 6 | 8 | 3 | 5 | TP |
| 5 | SL | 6 | 8 | 5 | 7 | TP |
| 6 | SL | 4 | 7 | 1 | 5 | TP |
| 7 | SL | 5 | 8 | 3 | 5 | TP |
| 8 | SL | 6 | 8 | 2 | 7 | TP |
| 9 | SL | 1 | 6 | 1 | 3 | TP |
| 10 | SL | 3 | 7 | 2 | 6 | TP |
| 11 | SL | 8 | 9 | 3 | 6 | TP |
| 12 | SL | 4 | 8 | 3 | 6 | TP |
| Averaged score | | 5.0 (SD = 2.0) | 7.8 (SD = 0.8) | 2.8 (SD = 1.5) | 5.8 (SD = 1.2) | TP |

| Student Number (Group 2) | Start | TP Laparoscopy | | SP Laparoscopy | | Preference |
|-----------------------------|-------|----------------|----------------|----------------|----------------|------------|
| | | Seventh Trial | Twelfth Trial | First Trial | Sixth Trial | |
| 1 | SP | 5 | 7 | 7 | 7 | SP |
| 2 | SP | 6 | 8 | 4 | 6 | TP |
| 3 | SP | 2 | 9 | 3 | 9 | SP |
| 4 | SP | 5 | 8 | 3 | 9 | SP |
| 5 | SP | 6 | 9 | 4 | 7 | TP |
| 6 | SP | 4 | 6 | 1 | 3 | TP |
| 7 | SP | 8 | 7 | 2 | 4 | TP |
| 8 | SP | 7 | 9 | 2 | 8 | TP |
| 9 | SP | 2 | 8 | 2 | 8 | TP |
| 10 | SP | 4 | 6 | 1 | 9 | SP |
| 11 | SP | 6 | 8 | 4 | 8 | TP |
| 12 | SP | 4 | 8 | 2 | 7 | TP |
| 13 | SP | 1 | 5 | 3 | 8 | SP |
| 14 | SP | 4 | 8 | 2 | 7 | TP |
| Averaged score | | 4.6 (SD = 2.0) | 7.6 (SD = 1.2) | 2.8 (SD = 1.6) | 7.1 (SD = 1.8) | TP |

Abbreviations: SP, single port; TP, 2 port; SD, standard deviation.

^aThe start column shows the surgical technique that was started with. The preference column shows which technique was preferred after the training.

Study Outcome

Two students of group 2 who started with the SP configuration exceeded the maximum allowable trial time of 15 minutes and were excluded from the study. Table 1 shows how the 1st, 6th, 7th, and 12th trials were rated in terms of difficulty. Of the 26 students, 5 students reported that the SP configuration was easier than the TP configuration. All 5 students started the session with the SP configuration. Overall, the participants judged the last trial of the SP configuration as easier to perform than the TP.

The graphs in Figure 7 display the learning curves of the force and trial times during the 12 trials in group 1. Group 1 started the session with the TP configuration and switched half way to the SP configuration. In the TP configuration, the learning curve for the maximum force as well as the performance time decreased from 7.5 N (SD = 2.24 N) and 633 s (SD = 564 s) to 6.6 N (SD = 2.31 N) and 114 s (SD = 40 s), respectively.

In the SP configuration, the performance time drops from 379 s (SD = 183 s) to 199 s (SD = 99 s), whereas the maximum force stabilizes around the 9 N (SD = 2.7 N) on average.

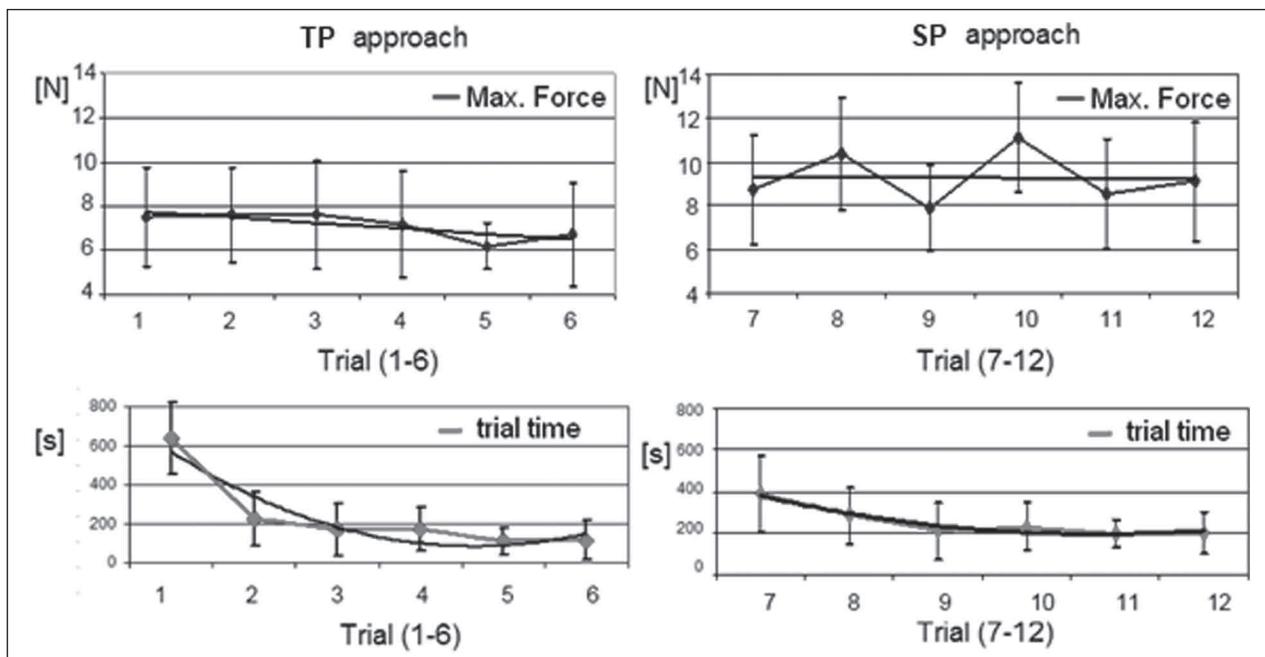


Figure 7. Learning curves for the trial time and maximum force in group 1. Group 1 switched from the TP to the SP technique after the sixth trial. To emphasize any trends, a second-order curve was fitted (black line) to each graph. Abbreviations: SP, single port; TP, 2 port.

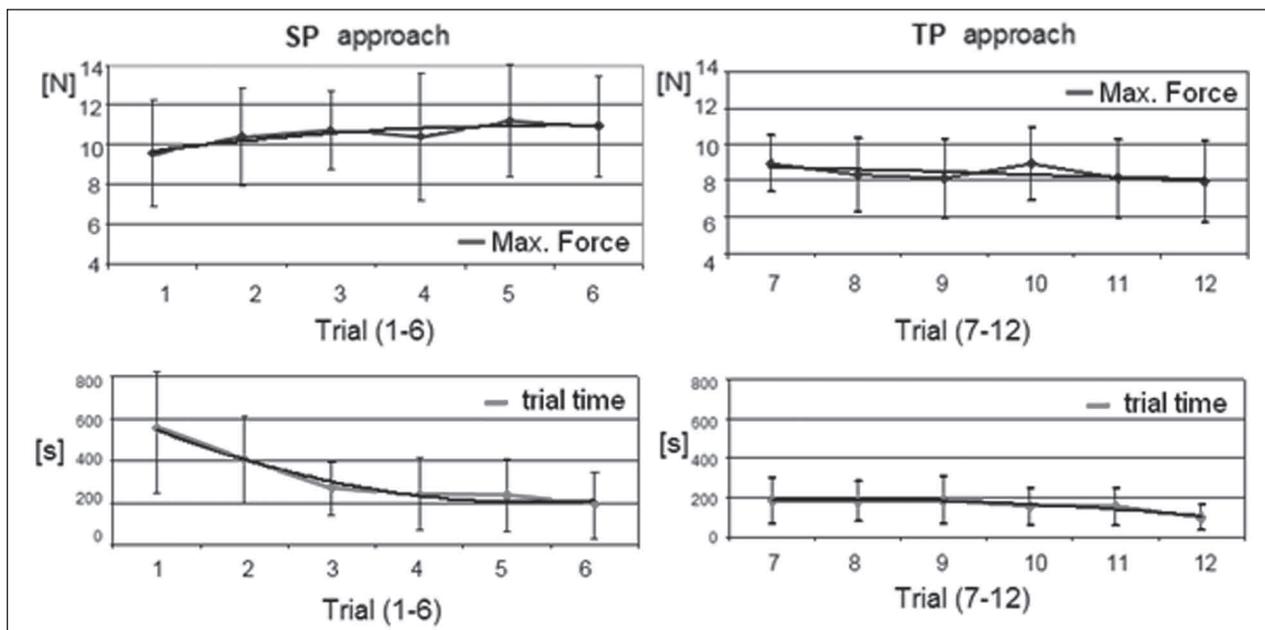


Figure 8. Learning curves of the trial time and maximum force of group 2. Group 2 switched from the SP to the TP technique after the sixth trial. To emphasize any trends, a second-order curve was fitted (black line) to each graph. Abbreviations: SP, single port; TP, 2 port.

The 2 graphs in Figure 8 display the learning curves for the maximum force and trial times during the 12 trials for group 2. Group 2 started the session with the SP configuration and switched half way to the TP configuration.

In the SP configuration, the learning curve for the maximum force increased from 9.5 N (SD = 2.6 N) to 11.0 N (SD = 2.5 N). The performance time decreased from 554 s (SD = 303 s) to 192 s (SD = 151 s), respectively. In the

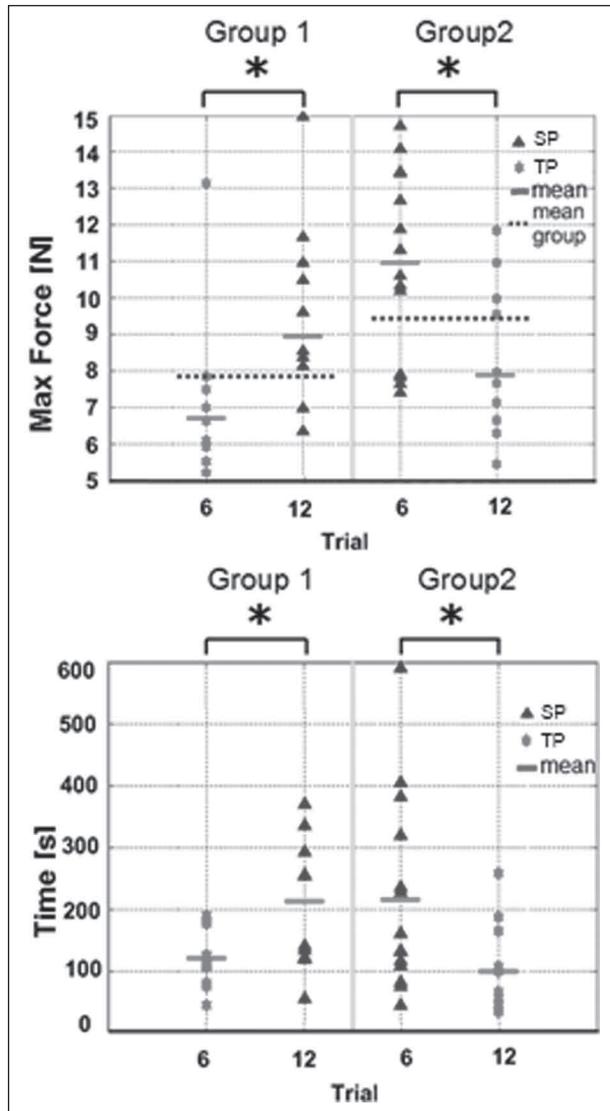


Figure 9. The maximum force (upper graph) and trial time (lower graph) for both groups at the end of each learning curve (eg, 6th and 12th trial)^a

Abbreviations: SP, single port; TP, 2 port.

^a —, The mean value; asterisk, the TP technique data, Δ , the SP data; ..., the averaged maximum force.

SP configuration, the performance time dropped from 187 s (SD = 115 s) to 101 s (SD = 68 s), whereas the maximum force dropped slightly from 9 N (SD = 1.6 N) to 7.9 N (SD = 2.2 N). Figure 9 shows the data from the 6th and 12th trials. The maximum force applied on the tissue in the TP configuration was noticeably lower in both groups compared with that in the SP configuration.

The students in Group 1 applied an average maximum force of 9.0 N (SD = 2.7 N) with the SP configuration and 6.6 N (SD = 2.3 N) with the TP configuration. The students in group 2 applied an average maximum force of 11.0 N (SD = 2.5 N) with the SP configuration and 7.9 N

(SD = 2.2 N) with the TP configuration. The average performance time differences between the SP and TP configurations were similar between groups. To understand the influence of the order in which a technique is learned on the tissue manipulation force, the SP and TP force data in Figure 9 were combined and averaged for each group (Figure 9, dotted line). The average maximum manipulation force in group 1 was significantly lower compared with that in group 2 (6.6, SD = 2.3 N, vs 9.0, SD = 2.7 N).

For the 5 students in group 2 who preferred the SP configuration above the TP configuration, the difference in tissue handling performance was investigated. At the end of the learning curve, the 5 students exerted a maximum force of 11.5 N (SD = 2.7 N) with the SP configuration and 7.7 N (SD = 1.9 N) with the TP configuration. The performance time was lower for the TP configuration compared with the SP configuration (mean [SD] = 183 [150] s vs 78.5 [53] s).

Discussion

The results show that on average, the SP configuration required 2.7 N more force and 87 s more time than the TP configuration during the last trial in both groups.

The significantly higher tissue handling force for the SP configuration compared with the TP configuration was found to be independent of the configuration mastered at the first attempt. Moreover, the learning curves suggest that the maximum manipulation force could increase over time during training with the SP configuration. This is in contrast to the slightly decreasing maximum manipulation force over time during training with the TP configuration.

The average maximum force data for each group indicate that the order in which both configurations are mastered by the students influences the overall tissue manipulation skills in terms of manipulation force. At the end of the learning curve, the overall average tissue manipulation force is significantly lower in the group that started training with the TP configuration compared with the group that started with the SP configuration. Therefore, if we only consider manipulation forces, it would be recommendable to master the laparoscopic technique for (new) surgical procedures before any single-access technique is applied. This approach is also commonly seen in current practice.

In the present study, the task environment was slightly different from the real situation because of the use of a fixed camera inside the box trainer. This may have affected the performance of the participants. However, the use of a real, nonfixed laparoscope inside the SILS trocar would induce additional restrictions on the movements of the instruments. The resulting increase in task complexity could result in more contact between instruments and camera, a higher mental load, and therefore higher tissue manipulation forces. It is therefore possible that in real SP surgery, larger effects of instrument configuration are found.

This study shows that straight instruments in a SP configuration minimize the range of motion and therefore increase the risk of collisions. Today, instrument manufacturers offer curved and double-curved instruments that might overcome part of these difficulties. Further studies are necessary to determine whether such altered instruments in a SP configuration can prevent high tissue handling forces.

In all studies that compared single-access surgery with standard laparoscopy, parameters based on time are used as objective performance measures.^{5,6} The findings in this study suggest that improvements in task time are not linked to improvements in tissue handling skills. These results correlate with our previous work.¹¹ In this study, visual force feedback dramatically reduced the tissue handling force during a conventional laparoscopic suture task. However, the performance time in the group that received visual feedback during training did not differ from that in the control group that did not receive feedback during training. Moreover, the learning curve in Figure 8 shows that even the opposite can be true.

For the group that started to train with the SP configuration, the task time reduced significantly, whereas the tissue handling skills deteriorated. These findings need to be taken into account if only time is used for skills evaluation.

For the 5 students in group 2 (ie, 3 female and 2 male) who preferred the SP configuration above the TP configuration, the difference in tissue handling performance was investigated.

The trial time and maximum force differences between techniques are not different from that for the rest of the students who preferred the TP configuration above the SP configuration. These results indicate that the choice for the preferred technique is not necessarily based on differences in instrument handling complexity. Other factors such as personal interest for new technology or the order in which the techniques were mastered could also influence the choice of a more complex technique. This is in line with the scoring of the SP configuration in Table 1. The final SP trial scored significantly higher if the SP configuration was mastered before the TP configuration.

Conclusion

The force data indicate that the increased complexity in instrument handling with straight instruments in a SP configuration increases the tissue manipulation force significantly. Furthermore, the order in which the 2 different instrument configurations are mastered by the students influences the overall handling force significantly.

Acknowledgment

The authors would like to thank all students, surgeons, and gynecologists for participating in this study. They thank all

students from Italy and the Netherlands for providing practical information about surgical suture tasks in box trainers.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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