Differences in abdominal force between conventional and single port laparoscopy

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Summary

In laparoendoscopic single-site surgery (LESS), only one single incision is used to introduce all instruments into the abdominal cavity. The introduction of multi-channel single-port devices enabled insertion of laparoscopic instruments and laparoscope through one single entry point instead of multiple entry points in conventional laparoscopic surgery (CLS). From recent studies is known that the distance between instruments influences the force exerted on tissue during manipulation. To investigate whether this force difference can also be found on the abdominal wall, a two-dimensional force measurement mechanism was designed and incorporated in a standard trainer box. The sensors were used to measure the abdominal force exerted by either the standard trocar or the single-port device on the artificial skin that mimics the abdominal wall. A randomized crossover study consisted of 16 students and three experienced surgeons was conducted. The subjects were asked to perform a task with two different instrument configurations (CLS and LESS) in randomized order. The results showed that when performing a force-related task with LESS configuration, the maximum abdominal force was significantly higher compared with the conventional two-port CLS configuration.

1 Background

Laparoendoscopic single-site surgery (LESS) is one of the latest trends in laparoscopic surgery aimed to combine all the trocar ports and extraction incision into one site. The required single incision is placed in the umbilicus resulting in a less visual scar. The first documented LESS was in 1997 [1]. This approach is gaining popularity mainly because of its improved cosmetic outcome [2]. So far LESS has already been applied in several surgical procedures such as cholecystectomy, appendectomy and gastric sleeve resection [3]. Despite the fact that LESS shares some similarities with CLS such as indirect vision, impaired depth perception and disturbed tactile feedback, it poses more technical challenges including further limited range of motion, continuous hand clashes and instrument collision [4]. It is unclear if this extra restriction on the instrument motion will result in higher force between instrument shafts, trocar and abdominal wall, causing a potential risk of injury around the incision. Previous research on the comparison between LESS and CLS has been conducted in a box trainer using different instruments and trocar ports [5-7]. For comparison, most studies used total time and task errors, or instrument motion. Only a few studies provided quantitative force-related measurements but were found not suitable to determine the difference in the abdominal force based on differences in instrument configuration [8-9]. Therefore, a new box trainer with force sensors able to measure the force between each individual trocar and surrounding artificial abdomen was developed. With this box trainer the forces exerted on the abdomen by the instruments in a CLS and LESS configuration can be accurately measured.

2 Materials and Methods

Participants

A total of 16 students, and three experts participated in the experiment. The students had no former systematic training in laparoscopy and lack real experience in the operating room. Experts included in the experiment are experienced surgeons in conventional laparoscopy and LESS. The order in which the CLS and LESS session were performed in the experiment was randomized for each participant.

Surgical Equipment

In the LESS configuration, the SILSTM port (Covidien Surgical, Norwalk, CT) was used to introduce two instruments into the box. The SILSTM port (Figure 1) is a typical multi-channel device consists of three solid ports, one for the camera and two for standard 5-mm straight instruments. In the conventional laparoscopic configuration, two standard 5-mm trocars (Endopath, Ethicon Johnson & Johnson) were used. In order to eliminate the influence different instrument have on the experimental results, the same standard straight surgical graspers (Endopath, Ethicon, Johnson & Johnson) were used for both configurations.

Experiment Setup

A modified box trainer for laparoscopic surgery was used for the experiments. (Figure 2), The top plate of the training box has two trocar ports for training of conventional laparoscopy and one extra trocar port in the middle for training with LESS. The top of the trainer box is covered with an opaque rubber cover, to prevent direction vision of the training task inside, comparable with real laparoscopy. A high resolution webcam (Trust, 30Hz) was used to capture a realistic top-view image of the task. The image was then displayed on a monitor that was placed above the trainer box on an ergonomic height. This enables an intuitive and
comfortable stand for the subject. A 2D force measurement system was developed, that consists of three rings and two sets of spring blades. To measure the movements of the rings hall magnets and magnets were used. In Figure 3-left is showed that the rings are inter connected by spring blades in such a way the rings act as two parallelogram mechanisms. The outer ring is now fixed to the top plate of the training box while the inner ring can move freely parallel to the top plate. Movement of the inner ring perpendicular to the top plate is restricted. According to Figure 3-Right, two pairs of sensors and magnets were used to measure the displacement of the inner ring. The stiffness of the spring blades connecting the rings determine the working range of the sensor. Based on earlier experiments and the most efficient measurement range of the hall sensors, a maximum inner ring displacement of 2 mm was found sufficient when a force of 15 N is applied by a spring balance. After calibration, the sensors were able to measure forces between 0 to 15N parallel to the abdominal plane with an accuracy of 0.1N.

A user interface was built in MATLAB 2010b to achieve data acquisition at a sampling frequency of 60Hz while displaying the image captured by the webcam. The recorded data can be saved as ‘.txt’ file in arbitrary units together with a corresponding time vector.

A 3d printed task board with pins on top was fixed on a platform inside the box trainer, with an emphasis on precision, eye-hand coordination, dual-hand maneuverability and depth perception. Both time for completion and abdominal force were recorded.

**Task 2: Tractive Force Task.** The second task was based on WebSurg videos of LESS procedures and designed and validated in a previous study [4]. It consisted of a worm-like silicone string, a small ring and a pin. The ring, pin and one side of the silicone string were fixed on the task board. The ring and pin were partially hidden under a highly elastic silicone layer so as to mimic the blocked view by organs and connective tissue in real scenario. For successful completion, the silicone worm has to be navigated through a ring, and finally hooked on the pin with the hole on the other end of string. Cooperation between instruments in both hands is required at all times in this task. Figure 5 shows the task before and after it was completed. Both time and abdominal force were recorded.

![Figure 2. Trainer box for CLS and LESS configuration](image2)

![Figure 3. Abdominal force measurement mechanism](image3)

**Training Task**

**Task 1: Transfer and Position** (figure 4). A 3d printed task board with pins on top was fixed on a platform inside the box trainer. To complete the task successfully, the subject needs to place three plastic tubes over three pins. The tubes are picked up with the left instrument, then transferred to the right instrument in open space, and finally placed on top of the target pins. This task was modified from validated transfer task in FLS (Fundamentals for Laparoscopic Surgery) box

![Figure 4. Task 1 grasp, transfer and placement on pin](image4)

![Figure 5. Task 2 grasp, transfer and placement on pin under tractive force](image5)

**Protocol**

The 19 participants were randomly assigned to two groups. The participant was informed of both configurations, and allowed to exercise with the instrument outside the box to get familiar with the usage of the instruments. In group 1, participants started with the CLS configuration for three trials, and then switched to the LESS configuration for the remaining three trials. Between the repetitions there was a short break of 2 minutes. After the first three trials, the participant was asked for finish a questionnaire concerning the frustration level of that configuration. In group 2, participants started with the LESS configuration. Ten subjects performed on task 1 while the remaining nine subject performed all measurements on task 2. The protocol is illustrated in Figure 6.

By dividing subjects into two groups with opposite order of configurations to be trained, the influence of the skills obtained with CLS on LESS and vice versa can be investigated. For each participant, there were two questionnaires (standard NASA Task Load Index) to be answered concerning the task load of the two different configurations.
Data Analysis

Time and abdominal force were measured for all tasks in all configurations. The abdominal force was calculated based on forces measured by sensors in orthogonal directions and defined as the square roots of $F_x$ and $F_y$. The maximum absolute force was considered as the maximum value in the absolute force vector.

All data were processed and analyzed using MATLAB. The statistical differences between the performances in two configurations were calculated with the two-tailed paired t-test. The differences in work load between the two configuration were also summarized. A p-value less than 0.05 was taken to indicate a significant difference.

3 Results

Table 1 shows the results of total task time and abdominal force divided over both task type and starting order. Of the 19 participants, only one student reported a low task load for the LESS configuration when starting with the CLS configuration followed by the LESS configuration. Overall, the participants reported a low task load for the CLS session.

The participants in task 1 applied an average maximum abdominal force of 2.68 N (SD=0.2) at the left trocar site, 3.98 N (SD=1.9) at the right trocar site in the CLS session, and 4.49 N (SD=0.9) at the single port site in the LESS session.

In task 1, the maximum abdominal force applied in the LESS session was noticeably higher compared with the CLS session when starting with the CLS session (left: $p<0.01$; right: $p=0.02$). This is not the case in the group starting with the LESS session in task 1 where no significant difference was found between the right trocar site and single port site ($p=0.88$).

When comparing the abdominal force in task 1 regardless of the starting order, it is significantly higher in the LESS session than that at the left trocar site in the CLS session ($p<0.01$). Between single port site and right trocar site no significant difference was found ($p = 0.38$).

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Looking at all participants from both groups together in task 2, the participants applied on average a maximum abdominal force of 3.5N (SD=0.6) at the left trocar site, 5.9 N (SD=2.4) at the right trocar site in the CLS session, and 9.4 N (SD=1.6) at the single port site in the LESS session.

From the results of task two a significant difference was found between the maximum abdominal force in the LESS session and CLS session (left: p<0.01; right: p<0.01). There was no significant different between the task time of the CLS session and LESS session in both tasks (task 1: p=0.87; task 2: p=0.07).

4 Interpretation

Figure 7 indicates that the starting order in which the different instrument configuration is mastered does not necessarily have an influence on the abdominal force in this crossover study. The instrument configuration itself however highly influences the abdominal force in task 2.

Although the results indicate that the average maximum abdominal force applied in the LESS session is significantly higher than that applied in the CLS session in task 2, this is not the case for task 1. One reason can be that task 1 mainly requires accurate position control during the grasping motions and basic movement of the instruments with minimal contact between the tip and the task board. In task 2 however, force control plays an important role since one instrument is constantly under tractive force while the other is used for support and guidance of the silicon-worm. Therefore, this study shows that if straight instruments in a LESS configuration are used for a (surgical) task that require collaboration between two instruments under traction, the force exerted by the trocar on the abdominal wall increases.

In this study, straight instruments and a SILSTM single port device were used. However, besides standard straight instruments, pre-curved and articulated instruments are now commercially available to overcome the limited range of motion encountered in LESS. Also, besides SILSTM port, different types of multi-channel single port devices are promoted by manufacturers. The choice of instrument and single port device often depends on each surgeon’s preference. Although all manufacturers claim that their set of instruments is better than others, more research is required to indicate if risks occur due to high forces on the abdominal wall. Moreover, forces exerted by the instruments on the patient are generated by the surgeon’s arms. Especially in combination with larger instruments and difficult arm positions common in laparoendoscopic single-site surgery, studies should also focus on the influence on the ergonomics of the operating surgeon.

In previous literature concerning the comparison between training in CLS and in LESS, mainly the difference in task time and task error are used as performance measures. The findings in this study suggest that better performance in time are not necessarily guarantee better performance in force-related parameter such as abdominal force. Similar results have been seen in the tissue manipulation force [4].

References