The physical workload of surgeons
A comparison of SILS and conventional laparoscopy.
C.J. Alleblas
S. Velthuis
T.E. Nieboer
C. Sietses
D.F. Stegeman
ABSTRACT

Background
As extensively reported in the literature, laparoscopic surgery has many advantages for the patient. Surgeons, however, experience increased physical burden when laparoscopic surgery is compared with open surgery. Single-incision laparoscopic surgery (SILS) has been said to further enhance the patient’s benefits of endoscopic surgery. Because in this surgical technique only 1 incision is made instead of 3 to 5, as in conventional laparoscopic surgery (CLS), it is claimed to further reduce discomfort and pain in patients. Yet, little is known about its impact on surgeons. This study aims to contribute by indicating the possible differences in physical workload between single-incision laparoscopy and CLS.

Methods
A laparoscopic box trainer was used to simulate a surgical setting. Participants performed 2 series of 3 different tasks in the box: one in the conventional way, the other through SILS. Surface electromyography was recorded from 8 muscles bilaterally. Furthermore, questionnaires on perceived workload were completed.

Results
Differences were found in the back, neck, and shoulder muscles, with significantly higher muscle activity in the musculus (M) longissimus, M trapezius pars descendens, and the M deltoideus pars clavicularis. Questionnaires did not indicate any significant differences in perceived workload.

Conclusion
Performing SILS versus CLS increases the objectively measured physical workload of surgeons particularly in the back, neck, and shoulder muscles.
INTRODUCTION

Since the introduction of laparoscopic surgery in the late 1980s, the advantages over open abdominal surgery have been extensively studied and published. It has been shown that laparoscopic surgery results in faster recovery, shorter hospital stay, less postoperative pain, and improved cosmetic results.\(^1\)\(^-\)\(^5\) Recently, single-incision laparoscopic surgery (SILS) was introduced to further enhance these benefits. This type of surgery permits operations to be performed entirely through 1 entry, generally an umbilical incision.\(^6\) From several studies, there are indications that SILS, compared with conventional laparoscopic surgery (CLS), results in less pain shortly after surgery and improved body image and cosmesis.\(^7\),\(^8\)

In contrast to the obvious patient benefits of laparoscopic surgery, not long after its introduction, it turned out that it has an increased burden to the surgeon.\(^9\) Many surgeons experience fatigue and physical discomforts primarily located in the back, neck, and shoulder regions during or after laparoscopic surgery.\(^10\)\(^-\)\(^13\) Less ergonomic human-product interaction,\(^10\),\(^14\),\(^15\) longer duration of surgery,\(^16\)\(^-\)\(^18\) loss of binocular vision,\(^9\) and limited freedom of movement\(^19\),\(^20\) are all reported problems encountered in laparoscopy and are often stated as mentally or physically burdensome.

With SILS, the mobility of the surgeon is even further restricted because of the single-access port. Furthermore, the counterintuitive control of instruments as a result of the crossing at the access port requires a lot of experience and sensory motor skills.\(^21\)

To our knowledge, little research has yet been conducted on the impact of the potential differences in the physical workload of surgeons between SILS and CLS. A previous study showed that SILS is associated with inferior performance and subjectively assessed higher workload.\(^22\) In addition, a related study comparing natural orifice transluminal endoscopic surgery (NOTES) with CLS showed that performing NOTES required substantially higher muscular workload.\(^23\) Exposure to excessive physical workload may result in muscle fatigue or musculoskeletal disorders, which in turn may well cause reduced productivity or absenteeism. In addition, fatigue or musculoskeletal disorders may affect performance of precision tasks,\(^24\),\(^25\) which may adversely affect the quality of care and patient safety. Therefore, it is of importance to address the physical load of the surgeon. In this study, we aim to determine the possible differences in physical workload between SILS and CLS. We hypothesised that the further restricted mobility and the counterintuitive control of instruments in SILS lead to an increase in physical workload compared with CLS.
METHODS

Participants
A total of 10 Dutch surgeons and surgical residents, 9 men and 1 woman, who were familiar with laparoscopic surgery, were recruited to participate in this study. All participants were right-hand dominant. The study was approved by the ethics committee of the faculty of human movement sciences (VU University, Amsterdam) and all participants signed an informed consent form prior to participation.

Experimental setup and procedure
A laparoscopic box training system (Lapstar, Camtronics BV, Son, Netherlands) was used to simulate a surgical setting (figure 1). Participants had to carry out a series of 3 tasks, once by CLS and once by SILS. The sequence in surgical technique was randomised between the participants. The order of tasks was not randomised to standardise the tasks between participants and technique. The first task involved “walking” up and down a numbered textile strap by alternately grasping it with the left and right laparoscopic graspers (task 1; figure 2a). The second task was to move a coin from one position to the next while in the meantime the coin had to be transferred between the 2 graspers (task 1; figure 2b). The third task involved a suture trail that had to be completed with 1 grasper and 1 needle holder, the latter controlled with the dominant hand (task 3; figure 2c). All 3 tasks were performed for 5 minutes consecutively without a break.

Figure 1. Laparoscopic box training system (http://www.lapstar.nl)
In between the series, the participants were given 5 minutes of rest. Prior to the experiment, the participants had the opportunity to familiarise themselves with the tasks by practicing it for a fixed time of 1 minute for task 1, and 2 minutes for task 2 and 3. Participants were instructed to perform each task on their highest pace without errors. In case of early completion of the task, it was repeated until the 5-minute performance time had passed.

Figure 2. Tasks: “Walking” a textile strap (a), coin replacement (b), and the suture trail (c)

Data collection
With a 16-channel portable electromyography (EMG) acquisitions system (Porti, TMSi, Enschede, Netherlands), surface EMG was measured bilaterally from 8 muscles by using pairs of disposable Ag/AgCl surface electrodes (Ambu, Blue Sensor N, Ballerup, Denmark). The muscles (table 1) were chosen on the basis of outcomes of previous research on the perceived discomfort during laparoscopic surgery and differences in posture and movement between CLS and open surgery.
Table 1. Included muscles for the electromyography measurement

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Body part location</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. longissimus</td>
<td>Back</td>
</tr>
<tr>
<td>M. trapezius; pars descendens</td>
<td>Neck/shoulders</td>
</tr>
<tr>
<td>M. trapezius; pars transversus</td>
<td>Back</td>
</tr>
<tr>
<td>M. deltoideus; pars clavicularis</td>
<td>Shoulders</td>
</tr>
<tr>
<td>M. teres major</td>
<td>Back</td>
</tr>
<tr>
<td>M. extensor carpi radialis</td>
<td>Arms</td>
</tr>
<tr>
<td>M. flexor carpi ulnaris longus</td>
<td>Arms</td>
</tr>
<tr>
<td>M. flexor pollicis brevis</td>
<td>Thenar</td>
</tr>
</tbody>
</table>

*M. musculus*

After proper skin preparation, the electrode pairs were attached with an interelectrode distance of 20 to 25 mm over the muscle bellies. The EMG signals were band-pass filtered between 10 and 500 Hz and digitalised with a sample rate of 2000 samples/s (LabVIEW, National Instruments Corp, Austin, TX). To record the posture and movement of the participants, a camera (Kodak Playsport Zx5, New York, NY) was placed approximately 0.5 m behind and 1.5 m to the side of the box trainer. Both the box trainer and the participant were filmed, with the participants being filmed from their knees to their head. Recordings were made only to ensure that abnormal findings or sudden extreme changes in the EMG signals could retrospectively be explained based on possible abrupt changes in posture or movements irrelevant to the tasks.

The subjectively experienced workload was measured by means of a questionnaire. Participants were asked to fill in the questionnaire at 3 time points: first, at the start of the experiment, as an indication of the baseline physical and mental condition, and then 2 other times, immediately after the CLS and the SILS procedure, to provide an indication of the demands of the performed surgical technique. The questionnaire involved 3 rating scales. First, the Rating Scale Mental Effort was used to compare the mental costs of executing the series of tasks by means of CLS versus SILS. The Borg Rating of Perceived Exertion CR10 scale was used to compare intensity levels of both surgical techniques. Finally, the body part discomfort scale was used to detect feelings of discomfort in which severity of discomfort was also rated on the Borg CR10 scale.
Data analysis

All files were analysed by means of written protocols in MATLAB 2010 (The Mathworks, Inc, Natick MA). The first 10 s of each measurement were removed because of irrelevant motions that participants often made in the start-up phase of each task. The raw EMG signals were then band-pass filtered between 100 and 500 Hz to remove movement artifacts, ECG contamination, and any interference from the mains and to also improve the relation with muscle moments. Root mean square (RMS) amplitudes were then calculated with a moving smoothing window of 500 ms. The average RMS amplitudes were calculated. Because this study involved paired observations, all initial values associated with CLS were used to normalise the data. The values associated with SILS were converted to a percentage of the initial CLS values. The equation below expresses the normalised average RMS amplitude for SILS for each individual muscle in percentage difference from the CLS value.

\[
\text{RMS}_{\text{SILS}}(\%) = \left( \frac{\text{RMS}_{\text{SILS}}(\mu V)}{\text{RMS}_{\text{CLS}}(\mu V)} - 1 \right) \times 100.
\]

Statistical analysis

Statistical analysis was carried out using SPSS 20 (SPSS, Inc, Chicago IL). Average RMS amplitudes were analysed by using a 2 × 3 (surgical technique × task) repeated-measures ANOVA. Bonferroni adjustment was used in the pairwise comparisons of the main effects for surgical technique and tasks. Scores on the Rating Scale Mental Effort and Borg Rating of Perceived Exertion Scale were analysed by means of a 1-way repeated-measures ANOVA. A p-value of < 0.05 was considered statistically significant.

RESULTS

In all, 6 surgeons (males) and 4 surgical residents (3 men, 1 woman) participated in the study. Characteristics of the study participants are shown in table 2. Data from a total of 14 out of 16 muscles were found useful for analysis. Because of the releasing electrodes in the thenar, bilateral measurements on the M pollicis brevis had to be excluded.
compared with task 1 (p < 0.05). Furthermore, a significantly increased difference in muscle activity in the left M longissimus was found between SILS and CLS when task 3 was performed compared with task 2 (p < 0.05), and a significantly increased difference in muscle activity in the right M extensor carpi radialis was found between SILS and CLS when task 2 was performed compared with task 1 (p < 0.05).

**Table 2. Participants descriptive summary**

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>SILS (h/wk)</th>
<th>CLS (h/wk)</th>
<th>Other surgery (h/wk)</th>
<th>Experience (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeons (n = 6)</td>
<td>44.8 [33-52]</td>
<td>3.2 [0-8]</td>
<td>9.0 [4-16]</td>
<td>11.2 [6-20]</td>
</tr>
<tr>
<td>Surgical residents (n = 4)</td>
<td>31.3 [28-33]</td>
<td>0.8 [0-2]</td>
<td>9.5 [2-14]</td>
<td>8.5 [8-10]</td>
</tr>
</tbody>
</table>


*Numbers are expressed as mean [range].

xDefined as years of being consultant in surgery and years of training of residents.

**Muscle activity**

Summary data of the differences in muscle activity are presented in table 3. Significant main effects of surgical technique on muscle activity were found in the back, neck, and shoulder muscles. The use of SILS compared with CLS significantly increased the average muscle activity of the right M longissimus and both the M trapezius pars descendens and the M deltoideus pars clavicularis bilaterally (p < 0.01). Furthermore, a significantly increased difference in muscle activity in the left M longissimus was found between SILS and CLS when task 3 was performed compared with task 2 (p < 0.05), and a significantly increased difference in muscle activity in the right M extensor carpi radialis was found between SILS and CLS when task 2 was performed compared with task 1 (p < 0.05).
The use of SILS compared with CLS significantly increased the average muscle activity of muscles. The effects of surgical technique on muscle activity were found in the back, neck, and shoulder.

Summary data of the differences in muscle activity are presented in Table 3.

**Table 3. Summary data of the percentage differences in average RMS amplitude**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Side</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Mean difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. longissimus</td>
<td>Right</td>
<td>50.3 ± 61.8</td>
<td>43.6 ± 49.4</td>
<td>45.5 ± 59.2</td>
<td>46.5 ± 9.9</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>8.2 ± 32.7</td>
<td>−1.5 ± 33.0</td>
<td>64.1 ± 91.3</td>
<td>23.6 ± 13.0</td>
<td>0.103</td>
</tr>
<tr>
<td>M. trapezius; pars descendens</td>
<td>Right</td>
<td>135.5 ± 161.8</td>
<td>227.9 ± 303.6</td>
<td>334.2 ± 273.5</td>
<td>232.5 ± 51.0</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>71.3 ± 114.2</td>
<td>180.5 ± 203.6</td>
<td>206.5 ± 207.8</td>
<td>152.8 ± 44.2</td>
<td>0.007</td>
</tr>
<tr>
<td>M. trapezius; pars transversus</td>
<td>Right</td>
<td>−32.4 ± 51.7</td>
<td>−6.7 ± 67.6</td>
<td>15.5 ± 64.0</td>
<td>−7.9 ± 14.0</td>
<td>0.588</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>−16.5 ± 26.2</td>
<td>−1.9 ± 26.8</td>
<td>−25.7 ± 29.7</td>
<td>−14.7 ± 6.7</td>
<td>0.057</td>
</tr>
<tr>
<td>M. deltoideus; pars clavicularis</td>
<td>Right</td>
<td>134.9 ± 189.8</td>
<td>206.2 ± 199.2</td>
<td>161.4 ± 151.2</td>
<td>167.5 ± 37.0</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>180.3 ± 302.8</td>
<td>133.8 ± 145.9</td>
<td>217.1 ± 149.2</td>
<td>177.1 ± 45.4</td>
<td>0.004</td>
</tr>
<tr>
<td>M. teres major</td>
<td>Right</td>
<td>15.9 ± 37.4</td>
<td>27.4 ± 47.6</td>
<td>19.8 ± 21.2</td>
<td>21.04 ± 9.4</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>19.8 ± 44.6</td>
<td>16.0 ± 31.7</td>
<td>−8.9 ± 36.3</td>
<td>9.0 ± 9.1</td>
<td>0.347</td>
</tr>
<tr>
<td>M. extensor carpi</td>
<td>Right</td>
<td>−12.6 ± 23.6</td>
<td>13.1 ± 23.5</td>
<td>−5.7 ± 20.9</td>
<td>−1.7 ± 5.5</td>
<td>0.762</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>6.8 ± 38.1</td>
<td>5.3 ± 43.4</td>
<td>2.3 ± 51.6</td>
<td>4.8 ± 12.7</td>
<td>0.715</td>
</tr>
<tr>
<td>M. flexor carpi</td>
<td>Right</td>
<td>−20.1 ± 30.3</td>
<td>7.2 ± 79.9</td>
<td>14.4 ± 49.7</td>
<td>0.5 ± 13.2</td>
<td>0.971</td>
</tr>
<tr>
<td>Ulnaris longus</td>
<td>Left</td>
<td>−23.8 ± 29.5</td>
<td>−1.8 ± 37.3</td>
<td>−0.8 ± 35.4</td>
<td>−8.8 ± 8.7</td>
<td>0.336</td>
</tr>
</tbody>
</table>

SILS single-incision laparoscopic surgery, CLS conventional laparoscopic surgery.

*Data are presented as mean ± standard deviation. Positive differences indicate higher muscle activity in SILS, whereas negative differences indicate higher muscle activity in CLS. Boldfaced results indicate significant differences between SILS and CLS.

**Perceived workload**

No significant differences were found in the ratings of mental effort (baseline: 53.1 ± 20.5; CLS: 54.1 ± 20.1; SILS: 57.5 ± 21.9; p = 0.703) or in the ratings of perceived exertion (baseline: 1.9 ± 1.2; CLS: 2.2 ± 1.1; SILS: 2.1 ± 1.0; p = 0.327). There were 6 participants who reported lower-back discomfort prior to the experiment (average severity level 1.8 ± 0.4). In 1 participant, the severity level of low-back pain increased from level 1 to 3 only after SILS. Furthermore, 1 participant reported discomfort in the left hand (severity level 2) prior to the experiment. After CLS, 2 participants reported complaints in the left hand (severity level 2), and 1 participant reported forearm and shoulder complaints (both with severity level 1). After SILS, 2 participants reported upper-back discomfort (mean severity level 1.5).
DISCUSSION

In this study, the objective and subjective physical workload in CLS and SILS were examined. Previous research already indicated that CLS is associated with more awkward movements of the upper extremities and a more static posture compared with open surgery.\textsuperscript{20} In addition, physical discomfort and fatigue are frequently reported after laparoscopic operations.\textsuperscript{10-13} Where many studies draw a line between open, laparoscopic, and robotic surgery, this study provides additional information in terms of the differences between SILS and CLS. We found that on average, SILS resulted in objectively higher physical load in the back, neck, and shoulder region. Findings are consistent with the study by Esposito et al.\textsuperscript{30} In their comparative study, it was observed that SILS surgeons suffer from musculoskeletal disorders after each SILS procedure, whereas surgeons performing CLS only suffer from musculoskeletal disorders after long procedures. It was concluded that SILS seems to have worse ergonomic circumstances compared with CLS.\textsuperscript{30}

The significantly increased muscle activity in the right M longissimus, the M trapezius pars descendens bilateral, and M deltoideus pars clavicularis bilateral is consistent with the cross-hand technique. Absence of differences in the upper-extremity muscles may well explain that the restriction of the single access port is compensated by a postural difference in which the shoulders are elevated and the mobility of the upper arms is restricted in a more endorotated position.

In several studies, a predominant number of respondents report experiencing physical discomforts in the back, neck, and shoulders as a consequence of minimally invasive surgery.\textsuperscript{10-13} In contrast, participants in this study primarily reported physical discomforts in the lower back. This might be related to the short duration of the tasks. In addition, questions on physical discomfort in other studies concerned the 12-month prevalence, whereas our questionnaire data were a reflection of the physical state only at the time of measurement.

Performing laparoscopic surgery requires a relatively low level of muscle activation for an extended period of time. One of the risks of performing at a low level of muscle activation is the continuous activation of lowthreshold, less-fatigable, small (type I) motor units. Therefore, the risk of fatigue is of particular concern for the long term in regard to deterioration at the central level,
which eventually may well affect the coordination of movements.\textsuperscript{31} Taking into account the results of previous studies, the increased level of muscle activity found during SILS could result in an earlier surpass of the comfort limit of the surgeon compared with CLS.\textsuperscript{30} This may partly explain the finding by Trastulli et al. in their metaanalysis of SILS versus CLS in cholecystectomy, where it was shown that SILS resulted in more procedure failures and more blood loss and took longer to perform.\textsuperscript{32}

This study had some potential limitations. First, regarding the measurement setup, measurements were based on a fixed time instead of achievements. By coupling the EMG measurement to the number of succeeded completions within a certain time, or vice versa, coupling the amount of time necessary for a certain number of completions allows for more distinction between participants. In addition, the measurement setup differed from the clinical setting regarding symmetry. During the performance of the tasks in the box, the participant stood right in front of it, while during in vivo laparoscopic surgery, the surgeon is always positioned to the side of the workspace, resulting in a different, and frequently more asymmetric, body posture. Furthermore, the amount of experience differed between the participants, from surgical residents to surgeons who had performed laparoscopic surgery for approximately 20 years. However, these interindividual differences enhance the significance of the differences found in muscle activity. A follow-up study might focus on possible differences between experienced and nonexperienced surgeons by taking a larger sample for both categories. Regarding the technical part of EMG analyses, measurements on the M pollicis brevis had to be excluded. Based on the results of the M extensor carpi radialis and the M flexor carpi ulnaris longus, we expect no differences in muscle activity in the thenar.

CONCLUSION

In conclusion, in this study, we found that clear differences in physical workload between SILS and CLS do exist in trunk, neck, and shoulder muscles, with a higher muscle activity during SILS. Repeated measurements in the operating room would provide valuable information, in addition to this study. In the fast-evolving field of minimally invasive surgery, fitting the work environment
and schedule to the changes in physical demands on the executive surgeon is of great importance to avoid performance degradation and maintain patient safety.
REFERENCES

24. Huysmans MA, Hoozemans MJ, van der Beek AJ, et al. Fatigue effects on tracking...


