Ergonomics and haptic feedback in minimally invasive surgery

Chantal Alleblas
The research presented in this thesis was conducted at the department of Obstetrics and Gynecology of the Radboud university medical center, Nijmegen, the Netherlands. Parts of the research presented in this thesis were funded by occupational disability insurance company MOVIR, the Dutch Working Group for Gynecological Endoscopy (WGE), and European Regional Development Fund (ERDF; in Dutch: Europees Fonds voor Regionale Ontwikkeling, EFRO).

Financial support for printing of this thesis was kindly provided by the Radboud university medical center, NVEC, and Endoscopic Force-reflecting Instruments BV.

ISBN
978-94-028-1028-8

Design/lay-out
Promotie In Zicht, Arnhem

Print
Ipskamp Printing, Enschede

© C.C.J. Alleblas, 2018

All rights are reserved. No part of this book may be reproduced, distributed, stored in a retrieval system, or transmitted in any form or by any means, without prior written permission of the author.
Ergonomics and haptic feedback in minimally invasive surgery

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. dr. J.H.J.M. van Krieken,
volgens besluit van het college van decanen
in het openbaar te verdedigen op dinsdag 5 juni 2018
om 14.30 uur precies

door

Chantal Christine Joëlle Alleblas
geboren op 23 juli 1989
te Wateringen
Promotoren
Prof. dr. M.E. Vierhout
Prof. dr. F.W. Jansen (Leids Universitair Medisch Centrum)

Copromotoren
Dr. Th.E. Nieboer
Dr. M.P.H. Vleugels (Ziekenhuis Rivierenland Tiel)

Manuscriptcommissie
Prof. dr. M.M. Rovers
Prof. dr. W.J.H.J. Meijerink
Prof. dr. J. Dankelman (Technische Universiteit Delft)
## Contents

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>General introduction and outline of the thesis</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2</td>
<td>Ergonomics in gynecologists' daily practice: a nationwide survey in the Netherlands</td>
<td>19</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery: a systematic review</td>
<td>35</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>The physical workload of surgeons: a comparison of SILS and conventional laparoscopy</td>
<td>71</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Ergonomics of laparoscopic graspers and the importance of haptic feedback: the surgeons’ perspective</td>
<td>85</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>The effects of laparoscopic graspers with enhanced haptic feedback on applied forces: a randomized comparison with conventional graspers</td>
<td>99</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Performance of a haptic feedback grasper in laparoscopic surgery: a randomized comparison with conventional graspers in a porcine model</td>
<td>113</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>General discussion</td>
<td>129</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>Summary</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>Samenvatting</td>
<td>155</td>
</tr>
<tr>
<td>Addendum</td>
<td>“Physician heal thyself” isn’t working</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td><em>An editorial comment on Chapter 3</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bibliografie</td>
<td>169</td>
</tr>
<tr>
<td></td>
<td>Dankwoord</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>Curriculum Vitae</td>
<td>175</td>
</tr>
</tbody>
</table>
1

General introduction and outline of the thesis
Minimally invasive surgery

During the mid-1800’s, scientists attempted to construct instruments to inspect organs in a minimally invasive manner via natural body orifices. Around 1900, a pioneering group of physicians, “Die Gesellschaft für Natur- und Heilkunde zu Dresden” developed groundbreaking inventions for minimally invasive abdominal surgery including an insufflator (Georg Kelling), cystoscope (Max Nitze), and trocar (Alfred Fiedler). These instruments enabled Georg Kelling to perform the first minimally invasive surgical procedure on a dog in 1901. Subsequently, the Swedish internist Hans Christian Jacobaeus conducted minimally invasive abdominal examinations in human patients. The minimally invasive approach appeared to be of great value for tubal sterilization in the 1970’s. Eventually, the first commended minimally invasive abdominal organ resection in a human patient, a resection of the gallbladder, was performed in 1985. Since then, traditional (open) surgical procedures, which are performed through a large incision in the abdominal wall, have been gradually superseded by minimally invasive surgical procedures, also known as laparoscopic surgery or keyhole surgery.

During laparoscopic surgery, one small incision is made through which an endoscope is inserted to inspect the abdominal cavity. Depending on the procedure, one to four additional small incisions are made to insert other surgical instruments like grasping and cutting devices. Initial concerns mainly involved the technical difficulty, a steep learning curve for the surgeon, longer operation times, and expensive instruments. However, alongside the increasing implementation of laparoscopic surgery in specialties such as gynecology, general surgery, and urology, comparative studies showed that laparoscopic surgery results in faster recovery, shorter hospital stay, less postoperative pain, and above all improved cosmetic results compared with open surgery. Nowadays, laparoscopic surgery is the primary approach used for many surgical procedures and the indications continue to broaden into many fields; e.g., surgical oncology.

In contrast to the generally accepted patient benefits of laparoscopic surgery, this surgical approach imposes limitations on the surgeon. First, there is a reduction in the degrees of freedom of instrument movement. During open surgery, instruments have six degrees of freedom because they can move freely in three-dimensional space. Additionally, the hands controlling these instruments can be positioned in any conceivable position, allowing tissue manipulation in any desired direction. In contrast, the use of trocars reduces the degrees of freedom available for laparoscopic instruments from six to four. Whereas laparoscopy does assist in both visualizing and approaching narrow and hard-to-reach cavities, the control of laparoscopic instruments requires very proficient hand-eye coordination. One of the challenges is the fulcrum-effect, which refers to inverting and scaling hand movements; i.e., in order to steer the instrument tip to the
right, the surgeon has to move his or her hand to the left. Additionally, surgeons have to scale the movement of their hands according to the location of the trocar alongside the shaft that serves as a pivot point. Besides these instrument-control difficulties, direct vision of the surgical field is eliminated. Surgeons must plan their actions based on two-dimensional visual feedback as displayed on monitors. In addition, direct haptic feedback (the sense of touch) is eliminated. This latter difficulty will be addressed in more detail later on in this chapter.

**Ergonomics**

Originally, the word ergonomics was derived from the Greek words ergon (work) and nomos (law), which can be interpreted as ‘the study of work’. The International Ergonomics Association defines ergonomics as “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance”. Ergonomics helps harmonize things that interact with people in terms of people’s needs, abilities, and limitations. Examples include guidelines for optimal office workplace settings and associated ergonomic table and chair designs, but also workspace design and balanced work times in assembly-line work among others.

To facilitate minimally invasive surgery, hospitals have re-equipped their surgical suites. The many variables, including table positioning, monitor placement, hand-held and long-shafted instruments, foot pedal controllers, and all the affiliated technological advances, have increased the complexity of the work environment and made it indispensable to study ergonomics in surgery. Indeed, alongside the initially slow but later progressively increased conduct of minimally invasive surgery, a parallel increase in publications mentioning ergonomics in minimally invasive surgery occurred, with cumulatively 114 PubMed citations in 1995, approximately 550 publications in 2005, and about 1900 citations in 2015.

Laparoscopic surgery imposes increased demands in terms of muscle activity in the upper extremities compared to open surgery. During laparoscopic surgery, surgeons face multiple constraints that directly expose them to risk factors for developing physical fatigue and musculoskeletal disorders. These risk factors include static body posture, repetitive movements, and force exertions from adverse positions. Moreover, the high level of task precision and time pressure further increases the workload. Recently, several studies quantified the physical burden of minimally invasive surgery and the occupational health hazards for surgeons. Strikingly, the reported prevalence of physical complaints among laparoscopic surgeons in survey studies are up to 73% and 88%. These are
alarmingly high rates, especially when physical fatigue or musculoskeletal disorders are known to affect the performance of precision tasks and may cause absenteeism or presenteeism (i.e., being present at work but with a loss of productivity). From the patients’ perspective, this could affect the quality of the surgery and their safety. What’s more, despite the availability of ergonomic guidelines (e.g., on table height settings or monitor positioning), there is a lack of awareness of these guidelines. Adjusting the workplace and equipment as well as adjusting the organization of work to comply with guidelines could potentially benefit the physical fitness of surgeons and therefore improve the quality of surgical care. In order to create or design such interventions and to develop recommendations for clinicians and designers specialized in surgical technology, insight into the magnitude and characteristics of the surgeon’s workload as well as their other needs is required.

In an attempt to reduce the number of abdominal incisions that are required to perform laparoscopic surgery, new methods were invented with the aim of further exploiting the benefits to patients. Examples are single-incision laparoscopic surgery (SILS), which allows the surgery to be performed through one entry point, generally an umbilical incision, and natural orifice transluminal endoscopic surgery (NOTES), a scarless approach performed through a natural opening (e.g., oral or rectal). SILS was introduced to improve cosmetics and reduce pain. However, from the surgeon’s perspective, it seems that SILS results in even more suboptimal ergonomics, mainly due to the fact that the freedom of space in which instruments are handled outside the abdomen is further impaired. One may question how much of the surgeon’s comfort and elbow room may be impaired for the patient’s benefit.

Evolving from a technology/commercially-driven approach, robot-assisted surgery was introduced as the next big milestone in minimally invasive surgery. In robot-assisted surgery, the surgeon sits in front of a console where he or she controls 3-4 laparoscopic instruments that are attached to a separate, larger device positioned alongside the surgery table. The system incorporates instruments with articulating graspers and three-dimensional vision. Alongside the discussion on cost-effectiveness, the drawback of robot-assisted surgery is the complete loss of haptic feedback. However, many surgeons report the superior ergonomic conditions of robot-assisted surgery as a major advantage compared to laparoscopic surgery. Several comparative studies revealed that robot-assisted surgery results in superior ergonomic circumstances compared to laparoscopic surgery. With the high purchase and maintenance costs of the current robotic systems, not all hospitals can afford such a device and, moreover, cost-efficiency has not been proven for most indications of robot-assisted surgery.
Technology

Minimally invasive surgery has introduced several technological innovations and challenges. As already mentioned, among these are the reduced degrees of freedom in instrument movement and the elimination of both direct visual and haptic feedback. To overcome the restriction in the degrees of freedom as compared to conventional open surgery, graspers were designed that allow the surgeon to reach around the corner. These so-called articulating instruments broaden the possibilities for surgeons by allowing them to bend the grasper tip up to 90 degrees relative to the shaft through a controller added to the instrument handle. Furthermore, where laparoscopic surgery was initially performed with non-mobile, low-resolution video systems, today there are ultra-high-definition and three-dimensional imaging systems, with ceiling-mounted monitors that can instantly be adjusted to any position. Another evolution was the introduction of mechanical energy devices for cutting and sealing. Compared to the electrosurgical devices initially available like monopolar and bipolar cutting and sealing forceps, more sophisticated instruments have found their way into clinical practice. Electronic energy devices for dissection and hemostasis were introduced, and were followed by ultrasonic (mechanical) energy devices, developed for the same purpose but without the need to use electricity in the patient.

Instrument handles are obviously the most important physical interface for surgeons while performing minimally invasive surgery. Together with the visual aspect of tissue properties, it is through the hand-handle interaction that information on applied forces and tissue properties are translated to the surgeons. Several types of instrument handles exist; e.g. scissors handles, axial handles and pistol handles. Examples of available handles are presented in figure 1. However, laparoscopic instruments and, more specifically, the bothersome instrument handles are known to cause physical discomfort and to cause hand injuries, especially injuries affecting the thumbs. Despite the availability of ergonomic criteria, most of the handles that are currently in use do not meet all these requirements. As suggested by Matern et al, during the design process of surgical instruments, muscle activity and task performance under dynamic conditions should be considered. In their study, the ergonomic aspects of five different types of handles was examined (axial, vario, multifunctional, ring and shank handle). With the use of EMG measurements, they found that the axial handle required significantly more muscle activity than all other handles. It is therefore questionable why until now most of the suturing devices still have an axial handle. This example is one among many that emphasize the importance of clinical and scientific input for research and development (R&D) departments of instrument manufacturers.
Haptic feedback involves the sense of touch. During open surgery, the surgeon can hold and palpate tissue with a gloved hand. In contrast, during laparoscopy, the surgeon can only manipulate tissue indirectly through the long-shafted instruments that offer inefficient mechanical connections. Consequently, haptic feedback is reduced in laparoscopic surgery compared to open abdominal surgery. Despite several technological attempts, devices for enhanced haptic feedback have not been implemented in clinical practice. This is remarkable because explicit attention was drawn to this topic over a decade ago, and the hand-assisted laparoscopic surgical (HALS) technique was introduced in the late 1990s specifically for the benefit of direct tissue palpation. HALS has been proposed as a sort of hybrid laparoscopic approach to nephrectomy, cholecystectomy, and hemicolectomy. Next to the laparoscopic trocars, a 4-6 cm incision is made to allow the surgeon’s hand to enter the abdominal cavity and palpate and present the relevant tissue. A recent systematic review showed that HALS can be considered as an alternative to laparoscopic colectomy, and that there was no difference or increased postoperative morbidity. In another study, HALS allowed access to the entire colon and rectum and allowed resection of the bladder, uterus, and ureter when these organs were involved. However, HALS implies a significant larger incision compared to conventional laparoscopic surgery with consequences regarding pain and cosmetic results for patients. Ideally, haptic feedback should be implemented in laparoscopic instruments in order to eliminate the need for larger incisions such as in HALS or while performing conventional open surgery. One may question whether haptic feedback is the missing link in laparoscopic surgery.

Figure 1 Laparoscopic graspers are equipped with various handle types. A: Scissors handle, small ring B: Scissors handle, large ring C: axial (inline) handle D: shank handle E: pistol handle, open lever F: pistol handle, closed lever.
Aims of the thesis

In the past decades, an advanced surgical environment has emerged. Numerous technical developments have contributed to the introduction and evolution of minimally invasive surgery, which entails many benefits for patients. However, the surgical team is exposed to high physical demands. Recent studies show that musculoskeletal disorders are almost universally present among surgeons specialized in minimally invasive surgical techniques. A good understanding of job content and identification of constraints in the instruments, equipment, environment, and organization in relation to human capacity is necessary to be able to reduce the physical demands and improve physicians’ well-being. Therefore, the first part of this thesis focuses on the specification of the physical workload in minimally invasive surgery and elaborates on the impact of different surgical approaches on the occupational health of the surgeon and possible implications for surgical performance. The second part of this thesis is dedicated to instrument design in general and the development of haptic feedback in laparoscopic surgery.

More specifically, the aims of this thesis are:

• To specify the extent of physical workload on surgeons (Chapters 2 and 3);
• To quantify the physical workload of single incision versus conventional laparoscopy (Chapter 4);
• To evaluate the importance of surgical instrument design (Chapter 5);
• To evaluate the relevance of haptic feedback during laparoscopy (Chapters 5 and 7); and
• To validate a new haptic feedback grasper (Chapter 6 and 7).

Outline of the thesis

In Chapter 2, an observational study on the current state of ergonomics in Dutch gynecological practice is described. Although in recent years much has been written about ergonomics in health care, a large percentage of gynecologists still experience physical complaints. Therefore, this study also focuses on the presence of work-related risks for developing physical symptoms. While there have been attempts to further optimize the quality of surgical care for patients, ergonomics for surgeons seem to be underdeveloped. In order to determine the actual impact of performing minimally invasive surgery on the surgeons’ physical health, a systematic review of the literature reporting the prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery is presented in Chapter 3. Objective differences in physical workload between SILS and conventional laparoscopy are presented in Chapter 4 as measured with electromyography (EMG).
The second part of this thesis focuses on haptic feedback during minimally invasive surgery and starts with **Chapter 5**. This chapter represents an up-to-date document regarding the ergonomics of laparoscopic graspers based on experts’ experiences and opinions. This chapter further highlights experts’ expectations regarding the clinical importance of haptic feedback in laparoscopic surgery. **Chapter 6** presents a randomized controlled crossover experiment through which three usability features of laparoscopic graspers, with and without enhanced haptic feedback, were tested, which included force control, tissue consistency interpretation, and confidence in decision-making. In **Chapter 7**, the functionality of the Force Reflecting Operation Instrument (FROI) compared to a conventional grasper was investigated in a porcine in-vivo setting.

In **Chapter 8**, the findings of the studies in this thesis are summarized and discussed and recommendations for future research are presented.
References


Ergonomics in gynecologists’ daily practice: a nationwide survey in the Netherlands

Chantal C.J. Alleblas
Margriet A.G. Formanoy
Reinier Könemann
Celine M. Radder
Judith A. Huirne
Theodoor E. Nieboer

WORK 2016;55(4):841–848
Abstract

Background: Gynecologists are exposed to multiple risk factors for developing physical complaints. To enhance the workplace ergonomics in gynecological practice, a more detailed insight in job content and associated demands is necessary to subsequently decrease the exposure to risk factors.

Objective: The aim of this study was to investigate the prevalence of physical complaints and the presence of ergonomic constraints in Dutch gynecological practice.

Methods: A questionnaire was distributed among the 1200 members of the Dutch Society of Obstetrics and Gynecology. It consisted of 52 Dutch questions derived from the validated Dutch Musculoskeletal Questionnaire.

Results: A total of 227 respondents completed the questionnaire (response rate 18.9%). Overall, 99.5% of the respondents rated their health status as reasonable or good. However, the twelve-month prevalence of physical complaints in one or more body part was 89.4%. Sustained adverse body postures were particularly reported for performing abdominal, and endoscopic surgery, and for assisting in vaginal surgery. Limited workspace, instruments, and patient size were reported by more than 60% of the respondents as constraints for adopting a neutral body posture during vaginal, endoscopic and abdominal surgery respectively.

Conclusion: The results emphasize the necessity of enhancing ergonomics in gynecological practice. Better ergonomic circumstances will most likely benefit both the health of the gynecologists as well as quality of surgical care.
Introduction

In the past decades, an advanced surgical environment has emerged. Numerous technical developments have contributed to the introduction and evolution of minimally invasive surgery (MIS). This type of surgery has many advantages for patients, when compared to (open) abdominal surgery, including: faster recovery, shorter hospital stay, less postoperative pain and improved cosmetic results. As a consequence of these better patient outcomes, the number of minimally invasive surgical interventions has increased. However, during MIS, the surgical team is exposed to a high level of mental stress and risk factors for developing musculoskeletal disorders (MSDs). The three major risk factors associated with MIS are static body posture, awkward repetitive movements and adverse force exertion. In addition, the workload is increased by a high level of task precision and time pressure.

Gynecological surgical procedures are conducted in the abdominal cavity and can be performed by open abdominal surgery, by endoscopic (minimally invasive) surgery or by vaginal surgery. Recent studies have indicated a high prevalence of MSDs among gynecological surgeons as well as among the entire surgical team including nurses and anesthesiologists. Prevalence of MSDs were specifically high for the back, neck and shoulder regions. Recently, data from the largest occupational disability insurance companies reveal that gynecologists have a 2.5 to 3 times higher rate of sick leave due to MSDs compared to other medical doctors (unpublished data, courtesy of MOVIR).

Overall, the high prevalence of MSDs and the rate of sick leave show an urgent need to study ergonomics in gynecological practice. Additionally, the negative effects on the health of gynecologists may well influence the quality of care. Sick leave of medical specialists, whether temporarily or permanently, means losing skilled and experienced work force, which reduces productivity and effectiveness. Moreover, MSDs and muscle fatigue may lead to impaired performance whereas task precision is highly important in surgery. Hence, patient safety may also benefit from studies on occupational health. A good understanding of job content and identification of constraints in the equipment, environment and organization in relation to human capacity is necessary to be able to reduce the physical workload. Therefore, the aim of this study was to investigate the prevalence of physical complaints and the presence of ergonomic constraints in Dutch gynecological practice by means of a nationwide survey.
Methods

This study was supervised by the board of the Dutch Working Group for Gynecological Endoscopy and approved by the board of the Dutch Society of Obstetrics and Gynecology. In November 2010, the twelve hundred members of the Dutch Society of Obstetrics and Gynecology were requested by e-mail to participate in the study. An explanation of the aim and importance of the study accompanied the questionnaire. By completing the questionnaire, participants declared their agreement with the use of their data for this study. Participants were able to take part anonymously. After one month, a reminder was sent.

The survey consisted of 52 Dutch questions derived from the validated Dutch Musculoskeletal Questionnaire (DMQ)\(^1\) (TNO, Work & Employment, Leiden, The Netherlands) and was subdivided into categories concerning: general demographics; general health status; physical complaints; physical workload; constraining factors; work organization and job satisfaction. Table 1 provides examples of questions.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Categorized example questions from the questionnaire (^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General demographics</td>
<td></td>
</tr>
<tr>
<td>· How many days do you work on average per week?</td>
<td></td>
</tr>
<tr>
<td>(numerical indication)</td>
<td></td>
</tr>
<tr>
<td>General health status</td>
<td></td>
</tr>
<tr>
<td>· How is your health in general?</td>
<td></td>
</tr>
<tr>
<td>(multiple choice: good; reasonable; moderate; poor)</td>
<td></td>
</tr>
<tr>
<td>Physical complaints (pain or discomfort)</td>
<td></td>
</tr>
<tr>
<td>· Have you experienced physical complaints during the last twelve months? (^b)</td>
<td></td>
</tr>
<tr>
<td>(multiple choice: yes, occasionally; yes, regularly; yes, long-lasting; no, never)</td>
<td></td>
</tr>
<tr>
<td>Work organization</td>
<td></td>
</tr>
<tr>
<td>· How many physical rest breaks do you have on a daily basis?</td>
<td></td>
</tr>
<tr>
<td>(numerical indication)</td>
<td></td>
</tr>
<tr>
<td>Job satisfaction</td>
<td></td>
</tr>
<tr>
<td>· I am proud of my profession.</td>
<td></td>
</tr>
<tr>
<td>(multiple choice: never, sometimes, often, always)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Questions translated from Dutch.

\(^b\) Question was subdivided for specific body parts: neck, shoulders, elbows, wrists, hands or fingers, upper back, lower back, hips, knees, calves, ankles and feet.
The items regarding general demographics are listed in table 2. General health, including physical fitness were assessed by means of a four-point semantic differential Likert-scale including statements: good, reasonable, moderate, poor. The questions on prevalence of physical complaints and associated body parts are comparable with the standardized Nordic Questionnaire on Musculoskeletal Disorders (NQMD)\textsuperscript{15} whereas the DMQ contains more detailed answer options to enable assessment of the nature and severity of complaints (i.e. yes/no answer options from the NQMD are replaced by the following four answer options: yes, occasionally; yes, regularly; yes, long-lasting; no complaints). The workload including perceived physical and mental fatigue was assessed by means of a four-point semantic differential Likert-scale including statements: not fatigued, somewhat fatigued, fairly fatigued, highly fatigued. The nature of the static workload in surgery was more specifically addressed by questioning the prevalence and duration (subscale: never, short, intermediate, long, continuously) of adverse working postures which have been identified as potential risk factors for developing physical complaints when exceeding (posture specific) temporal thresholds. To examine which elements are considered important constraints for adopting a neutral working posture, specific workplace components (also see figure 4) were assessed by means of yes/no (yes, this is a constraint; no, not a constraint) questions. Questions regarding work organization specifically addressed the working schedule (including duration of tasks, pausing, work variation and control options) by means of time indications and semantic multiple choice questions. Finally, job satisfaction was assessed by means of a four-point semantic differential Likert-scale including statements: never, sometimes, often, always.

Statistical analysis was carried out using the Statistical Package for the Social Sciences 20 (SPSS, Inc., Chicago IL, USA). For calculations related to specific job tasks, participants who did not perform those tasks were excluded from calculations regarding the particular task. In the descriptive data analysis, frequency counts, percentages, means, and standard deviations were obtained. Categorical data on posture were analyzed with the Friedman’s ANOVA and Wilcoxon signed-rank test. A $p$ value of $< 0.05$ was considered statistically significant.

**Results**

A total of 227 gynecologists completed the questionnaire (response rate 18.9%); among these were 47 residents. Demographics of the participants are summarized in table 2.

**General health**

On a four-point Likert scale, 99.5% of the respondents rated their state of health as reasonable (10.1%) or good (89.4%) and 97.4% rated their current physical fitness as reasonable (30.0%) or good (67.4%).
Regarding the twelve-month prevalence of physical complaints, 89.4% of all respondents indicated experienced physical complaints or discomfort in at least one body part. Besides, 61.7% reported three or more locations of physical complaints or discomfort. Furthermore, 5.3% reported absenteeism during the last twelve months as a consequence of these physical complaints.

The most frequently reported physical complaints involved the back (lower: 61.2%; upper: 33.5%), neck (55.1%) and shoulders (dominant side: 34.8%; non-dominant side: 28.6%), with a duration ranging from occasionally to long-lasting. Somewhat less frequently mentioned physical discomforts were experienced in the hands (dominant hand: 27.3%; non-dominant hand: 16.3%), knees (22.5%) and feet (23.3%). Figure 1 provides an overview of the twelve-month prevalence and duration of the most frequently reported complaints.

The prevalence of complaints during the preceding seven days had a more or less similar subdivision with the lower back as the most frequently indicated site of complaints. Overall, 63.4% of the respondents reported physical complaints in one or more regions.
Chronic complaints were reported by 25.6% of all respondents. The most common areas for chronic complaints involved back, neck, shoulders and hands. Chronic lower back complaints were reported by 11.5% of the respondents.

![Figure 1](image.png)

**Figure 1** The twelve-month prevalence of the most frequently reported physical complaints. Results are reported according to the duration of complaints (occasionally, black bar; regularly, diagonal striped bar; long-lasting, white bar)

**Physical workload**

Respondents were asked to mention their top three most physically demanding tasks. Surgery was indicated as the most demanding, followed by working in delivery rooms and performing outpatient clinic consultations respectively. On a four-point Likert scale ranging from 1: not fatigued to 4: very fatigued, the mean score for physical fatigue after a day of surgery, and performing outpatient clinic consultations was 2.43 (SD=.79) and 1.97 (SD=.78) respectively, while the average score for mental fatigue was 2.19 (SD=.85) and 2.53 (SD=.85) respectively.

Figure 2 shows the percentage of respondents reporting sustained (in terms of long or continuously), adverse postures for three types of surgery from the surgeon’s perspective; Figure 3 shows the same from the assistant’s perspective. Compared to vaginal and abdominal surgery, adverse postures were significantly longer maintained in the back (rotation), neck (lateral head flexion or rotation) and upper extremities during endoscopic surgery ($p < .01$). During abdominal surgery, strong flexed or extended postures in the neck and back were maintained for a significant longer period of time compared to both vaginal and endoscopic surgery ($p < .01$). For vaginal surgery, most adverse body postures were primarily reported to be maintained for short durations.

In contrast, reported adverse stances were significantly longer maintained during assistance of vaginal surgery compared to performing vaginal surgery in all investigated postures. During assistance of abdominal surgery, head rotation or lateral head flexion
and adverse postures of the upper extremities are significantly longer maintained compared to performing abdominal surgery. Otherwise, adverse postures of the upper extremities are significantly longer maintained by the surgeon compared to the assistant in endoscopic surgery.

**Figure 2** Sustained adverse postures while performing surgery (vaginal surgery, black bar; endoscopic surgery, diagonal striped bar; abdominal surgery, white bar).

* = significant higher prevalence of sustained adverse posture compared to both other surgery types, \( P < 0.01 \)
† = significant lower prevalence of sustained adverse posture compared to both other surgery types, \( P \leq 0.01 \)

**Figure 3** Sustained adverse postures while assisting surgery (vaginal surgery, black bar; endoscopic surgery, diagonal striped bar; abdominal surgery, white bar).

* = significant higher prevalence of sustained adverse posture compared to both other surgery types, \( P < 0.01 \)
† = significant lower prevalence of sustained adverse posture compared to both other surgery types, \( P < 0.01 \)

**Constraining factors**

Participants were asked to indicate which factors they consider important constraints for adopting a neutral posture during vaginal, endoscopic and abdominal surgery. Figure 4 provides an overview of the presented possible constraints and the percentage respondents indicating whether this was a limitation per type of surgery. Limited workspace (65.0%) was the most frequently mentioned constraining factor in vaginal surgery. Instruments (61.8%) and patient size (61.8%) were the most frequently mentioned constraining factors.
for endoscopic and abdominal surgery respectively. In addition, 56.6% of the respondents indicated monitors as a constraint during endoscopy.

**Work organization**

Respondents were asked to indicate which tasks they perform during the week and how much time they spend on those activities. For working in the operation room this was on average 6.8 (SD = 3.9) hours per week, with a mean consecutive time of 4.9 (SD = 2.3) hours. The average time for performing a single surgical procedure was 61 (SD=21), 60 (SD=29), and 76 (SD=32) minutes regarding vaginal, endoscopic, and abdominal surgery respectively. For obstetrics, respondents worked on average 9.7 (SD = 7.6) hours per week with a mean consecutive time of 6.2 (SD = 6.2) hours. Work in the outpatient clinic was done for 16.8 (SD = 6.2) hours per week on average with a mean consecutive time of 4.6 (SD = 1.8) hours. The total prevalence of working structural (70%) or occasional (24.7%) overtime was 94.7%. Only 12 (5.3%) respondents reported that they never work more than contractually stipulated.

Regarding rest breaks, the majority of respondents (61.7%) reported to take one physical break on a daily basis which on average takes 25 minutes (SD = 11). Overall, 47.6% is always or often fully rested after a break, whereas 52.4% sometimes or never returns to work fully rested.

Little attention is paid to the variation of labor since 70.0% of the respondents reported to never allow for alternation between high and low physically demanding activities. Similarly, this was the case for alternation between high and low mentally demanding tasks (66.5%).

Overall, the work was perceived as particularly hectic. A total of 81.1% of respondents indicated the work pace to be quite high on a regular basis. The majority of respondents
sometimes (49.3%) or often (37.4%) lack time to complete tasks within the predetermined schedule. In addition, the majority (54.2%) reported to be unable to adjust the work pace and 48.9% were unable to determine the sequence of work by themselves.

**Job satisfaction**

Notwithstanding the high workload, limited control options and usually working overtime, questions regarding job satisfaction reveal that 91.2% of the respondents were often (81.5%) to always (9.7%) satisfied with their job. Almost 90% were often (59.0%) to always (30.8%) enthusiastic about their profession and 94.7% were often (54.6%) to always (40.1%) proud on their job.

**Discussion**

We conducted a nationwide survey to study the prevalence of physical complaints and the presence of ergonomic constraints in the Dutch gynecological practice. The results show a high prevalence of physical complaints, emphasize the extent of static workload in surgery, and demonstrate the existence of several constraints impeding the interaction between gynecologists and their work situation.

Although respondents assessed their general health status mainly as reasonable or good, it was shown that physical complaints are highly common among gynecologists. Overall, we found a 12-month prevalence of 89.4% for experienced physical complaints or discomfort in one or more body parts. This number is in accordance with the reported 88.1% among gynecologic oncologists by Franasiak et al. (2012) and 86.9% among surgeons performing minimally invasive surgery in the study by Park et al. (2010).8,16

Surgery was indicated to be the most physically demanding subdivision, followed by working in the labor room and performing outpatient clinic consultations. Studies on operating room personnel10 as well as obstetric ultrasonologists17,18 show similarities in the most frequently reported areas for physical complaints, although complaints were less prevalent in the latter group. Yet, little research has been conducted, which specifically addresses the workload of labor room workers. Future research should address ergonomics in obstetrics, since this occupational group is exposed to comparable risk factors as nurses and physicians.19

Despite the limited workspace, vaginal surgery seems to be the most favorable type of surgery regarding the surgeons’ posture. In contrast, this study shows striking results for assistants’ working postures during this type of surgery. Assistants appear to be forced into adverse postures for a significant longer amount of time compared to surgeons.
during vaginal surgery. This might well be caused by trying to create an unrestricted view of the operating field while being hampered by the limited workspace and the position of the patient and colleagues. Creating an unrestricted view of the operating field has been indicated as an important constraint for scrub nurses in laparoscopic and abdominal surgery.\textsuperscript{20,21} Yet, in literature little is known about the physical workload of first assistants and scrub nurses during vaginal surgery. Additional studies should further evaluate ergonomics to search for potential optimization strategies.

The workload of robotic surgery was not addressed by this study. Recently, robotic surgery has gained a widespread acceptance and consequently this type of surgery is being increasingly more performed. Although early results show advantages in terms of less physical discomfort for the surgeon when compared to laparoscopic and abdominal surgery.\textsuperscript{22} Recent evaluations of robotic surgery reveal ergonomic deficits\textsuperscript{23} and also a high prevalence (72\%) of physical complaints among surgeons performing robotic surgery.\textsuperscript{24} Additional ergonomic research, including the field of robotic surgery, should contribute to this debate.

The majority of respondents indicated instruments, foot pedals and monitors as constraining factors for adopting neutral working posture during endoscopic surgery. The adverse effects of surgical instruments and equipment have been clearly demonstrated in previous research.\textsuperscript{6,25-29} This study shows that these ergonomic problems related to instruments and equipment are still encountered by the surgical team and emphasizes the necessity of ergonomic adjustments and application of guidelines.

Besides technical improvements, optimization may also be found in organizational structure and habits. Our results indicate that little attention is paid to alternation between high and low physically and/or mentally demanding tasks. Furthermore, the majority of respondents only take one physical break per day. This might be a direct consequence of the hectic work schedule. Implementation of short breaks may offer a good solution here for both the gynecologists as well as the quality of patient care. Engelmann et al. (2011) showed that taking a 5-minute work break every 25 minutes during pediatric laparoscopic surgery significantly reduces the surgeons’ stress, and preserves performance without prolongation of operation time.\textsuperscript{30} Moreover, no adverse effects in patients were found.\textsuperscript{31} Additionally, Dorion and Darveau (2013) showed significant effects of micro pauses on fatigue and accuracy. In their study, taking a 20 second break every 20 minutes during long surgical interventions significantly reduced the level of discomfort and fatigue and improved technical accuracy.\textsuperscript{32}

This study has some potential limitations. First, our response rate (18.9\%) was rather low. However, it is known that survey studies among physician specialists are challenging and prone to low response rates.\textsuperscript{33} In similar previous survey studies, which specifically address
the prevalence of physical complaints among gynecological surgeons, response rates between 6.4% and 68% were reported with a median response rate of 27.4%.\textsuperscript{7-9,24-26,34} Additionally, the questionnaire was quite long, which usually negatively affects response rate.\textsuperscript{35} Furthermore, our request clearly stated the aim of the study. Therefore, it is likely that particularly those experiencing physical complaints or discomfort or those interested in ergonomics were triggered to complete the questionnaire in order to contribute to better working conditions. As a consequence of selection bias, caution has to be taken into account when extrapolating the findings to the entire occupation group. Furthermore, it must be mentioned that length of sustained postures were not measured objectively. Consequently, the self-reported workplace exposure may over or under estimate the true extent of the problems.

In conclusion, our study emphasizes the necessity to enhance ergonomics in gynecological practice in order to reduce physical risk factors. Better ergonomic circumstances will probably benefit both the health of the gynecologists as well as quality of care.
References


Prevalence of Musculoskeletal Disorders Among Surgeons Performing Minimally Invasive Surgery: A Systematic Review

Chantal C.J. Alleblas
Anne Marie de Man
Lukas van den Haak
Mark E. Vierhout
Frank Willem Jansen
Theodoor E. Nieboer

Annals of Surgery 2017;266(6):905-920
Abstract

Objective: The aim of this study was to review musculoskeletal disorder (MSD) prevalence among surgeons performing minimally invasive surgery.

Background: Advancements in laparoscopic surgery have primarily focused on enhancing patient benefits. However, compared with open surgery, laparoscopic surgery imposes greater ergonomic constraints on surgeons. Recent reports indicate a 73% to 88% prevalence of physical complaints among laparoscopic surgeons, which is greater than in the general working population, supporting the need to address the surgeons’ physical health.

Methods: To summarize the prevalence of MSDs among surgeons performing laparoscopic surgery, we performed a systematic review of studies addressing physical ergonomics as a determinant, and reporting MSD prevalence. On April 15th 2016, we searched Pubmed, EMBASE, the Cochrane Library, Web of Science, CINAHL, and PsychINFO. Meta-analyses were performed using the Hartung-Knapp-Sidik-Jonkman method.

Results: We identified 35 articles, including 7112 respondents. The weighted average prevalence of complaints was 74% [95% confidence interval (95% CI) 65 - 83]. We found high inconsistency across study results ($I^2 = 98.3\%$) and the overall response rate was low. If all nonresponders were without complaints, the prevalence would be 22% (95% CI 16 - 30).

Conclusions: From the available literature, we found a 74% prevalence of physical complaints among laparoscopic surgeons. However, the low response rates and the high inconsistency across studies leave some uncertainty, suggesting an actual prevalence of between 22% and 74%. Fatigue and MSDs impact psychomotor performance; therefore, these results warrant further investigation. Continuous changes are enacted to increase patient safety and surgical care quality, and should also include efforts to improve surgeons’ well-being.
Introduction

The laparoscopic approach has become standard for many surgical interventions due to its benefits compared with open surgery, which include less postoperative pain, faster recovery, shorter hospital stay, and improved cosmetic results. Widespread implementation of laparoscopic procedures has led to increased studies of ergonomics in surgery. The field of ergonomics deals with the design and evaluation of job tasks, products, and environments to improve their compatibility with people’s needs, abilities, and limitations. In particular, physical ergonomics focuses on human anatomical, anthropometric, physiological, and biomechanical characteristics as related to physical activity.

The field of minimally invasive surgery (MIS) is continuously evolving. Newer techniques, such as natural orifice transluminal endoscopic surgery (NOTES) and single-incision laparoscopic surgery (SILS), have greater benefits for the patient, but may increase the physical workload for the surgeon. On the contrary, robotic approaches have been introduced. Debates surrounding robotic surgery mainly focus on the costs and patient benefits. However, another important issue is that robotic approaches may provide ergonomic benefits to the surgeon—enabling the surgeon to operate from a seated posture, and allowing more degrees of freedom for instrument movement and 3D vision.

Several ergonomic studies reveal that during laparoscopic surgery, surgeons face multiple constraints that directly expose them to risk factors for developing musculoskeletal disorders (MSDs). These risk factors include static body posture, repetitive upper extremity movements, and force exertion from adverse positions. Moreover, the workload is increased by the high level of task precision and time pressure. Physical demands differ between open and laparoscopic surgery and comparative studies have reported higher prevalences of physical complaints for laparoscopic surgeons. Recent studies report MSD prevalence rates of 73% to 88% among specialists in minimally invasive surgery. Relative to the general population, these numbers are excessively high. The Fourth European Survey on Working Conditions presents the prevalences of several MSDs, reporting a 24.7% prevalence of backache, 22.8% prevalence of muscular pain and 23% prevalence of neck and shoulder pain. A US-based study of a large occupational population reported a 20.8% prevalence of lower back pain. MSDs develop gradually and can affect different parts of the musculoskeletal system, including muscles, joints, and nerves. Laparoscopic surgeons mainly report issues involving their neck, back, shoulders, wrists, and thumbs. Symptoms associated with these MSDs predominantly include fatigue, pain, stiffness, and numbness. Such symptoms can affect task accuracy, potentially having an indirect impact on patient safety, which is the main priority in surgery.
In our present systematic review, the primary objectives were to determine the overall prevalence of MSDs among surgeons performing minimally invasive abdominal surgery, and to determine whether MSD prevalence varies according to body region and minimally invasive surgical method. The secondary objectives were to identify how MSD prevalence among surgeons impacts surgical performance, and to identify additional risk factors beyond the general ergonomic risk factors. Our present findings will provide insight into the contemporary magnitude and characteristics of MSDs among surgeons, which will help to design interventions, increase awareness, and to develop recommendations for clinicians and medical technicians.\(^\text{25}\)

**Methods**

To summarize the overall MSD prevalence among surgeons performing MIS, we conducted a systematic review following the PRISMA guidelines. The search strategy was developed by CA, AdM, and TN in consultation with a research librarian at the Radboud University Library. On April 15 2016, we performed a search in PubMed, EMBASE, the Cochrane Library, Web of Science, CINAHL, and PsychINFO. The following search terms were used (as Medical Subject Headings and Title/Abstract words): “Human Engineering” OR “ergonomics” OR “human factors” OR “occupational health” OR “workload” AND “surgical procedures, minimally invasive” OR “minimally invasive surgery” OR “minimal access surgery” OR “laparoscopy” OR “endoscopy” OR “Surgery, Computer-Assisted” OR “Robotics”. Appendix 1 includes the full search strategies per database. We set no limits regarding year of publication, language, or publication status and we applied no other additional filters after running the search in the consulted databases.

Our present review focused on MIS performed in the abdominal cavity—including general, gynecological, and urological surgery. This limitation was applied because these specializations entail similar task-physical and environmental characteristics and, therefore, carry similar risk factors for developing physical complaints. For inclusion, studies had to address physical ergonomics as a determinant, report the prevalence of MSDs (or physical complaints) as a study outcome, and be published as full-text articles in a peer-reviewed journal.

All studies identified in the initial database search were independently reviewed by 2 researchers (CA and AdM). First, the titles and abstracts were screened to identify all articles related to physical ergonomics in MIS. Next, the full-text articles were obtained to determine eligibility for final inclusion in the synthesis. Disagreements were discussed with a third researcher (TN), and resolved by consensus. Finally, the references of the included articles were checked for additional articles of interest.
We recorded the following data from the included studies: year of publication, population/sample size/response rate, type of surgery, applied questionnaire, and primary and other relevant outcome measures. The primary summary measure was the reported prevalence of physical complaints. Secondary summary measures included predictors for symptom development and impact on surgical performance.

To evaluate the conduct of the included studies, we used the 22-item Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist.26,27 Each reviewed article was assessed for all 22 items with 1 point given for each successfully addressed item, and a total score calculated as the sum of all items. Finally, we calculated the average score for all reviewed articles.

Finally, we performed random effects meta-analyses for both overall prevalence of physical complaints and body part specific prevalence. We calculated exact binomial confidence intervals (CIs) for the individual studies, and performed an arcsine transformation of the proportions for the meta-analyses. We expected to find high heterogeneity due to differences in the utilized questionnaires (validated or not validated), in the MSD definitions, and in the study time frames. Therefore, we pooled the individual prevalence rates using the Hartung-Knapp-Sidik-Jonkman (HKSJ) method for random effects.28 Heterogeneity was measured based on $I^2$ and prediction intervals. Analyses were conducted in R (version 3.0.1; R Core Team 2012), using the meta package.29

**Results**

The database search identified 7844 articles, of which 345 were primary research articles addressing physical ergonomics in MIS. Cross-reference checking identified 4 additional articles. Evaluation of full-text manuscripts led to the final inclusion of 35 studies. Figure 1 shows the PRISMA flow chart with detailed information regarding the selection process.

Study appraisal yielded an average STROBE score of 17.5 (range 11 – 20) out of 22. Efforts to address potential sources of bias were poorly explained in the method sections, with only 2 articles successfully fulfilling this item. Additionally, 7 articles failed to report the sample size, and 13 articles did not address the study limitations.

All included articles described survey studies, mainly using self-composed questionnaires. Four surveys reported integration of the Standardized Nordic Questionnaire for Musculoskeletal Symptoms30 (NMQ) or a modified version.31-34 Five surveys25,35-38 integrated the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) ergonomic questionnaire, as developed by the SAGES Ergonomic Task Force.39 To some extent, all
studies subdivided the involved body regions, or enabled the respondents to describe the affected body parts. The articles widely differed in the terminology used for MSDs (eg, musculoskeletal symptoms, discomfort, injuries, or problems) and in the descriptors used to characterize the nature of the MSDs (eg, pain, numbness, stiffness, and fatigue). Moreover, the time period for occurrence of complaints ranged from a point prevalence (during or immediately after surgery), to a 12-month prevalence, to having ever experienced symptoms. The marked duration or emergence of musculoskeletal symptoms also varied from intra-operatively; shortly after surgery; up to recurrent, persistent, or chronic.

Response rates ranged from 6.1% to 100%, with an average of 40.2%. Overall, the reviewed studies included 7112 respondents who were mainly laparoscopic surgeons who performed

---
prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery

procedures in general surgery, gynecology, and urology in both adult and pediatric patients. Three studies also included a subset of respondents (N=378) that were (scrub) nurses, general physicians, anaesthesiologists, or orthopedists.13,40,41 Where possible, data from those respondents were excluded from our meta-analyses.

Table 1 provides an overview of included studies with itemized primary and other relevant outcomes. Of the included articles, 26 reported an overall MSD prevalence among surgeons performing any type of minimally invasive abdominal surgery, which ranged from 20% to 100% with an average of 74%, and a 95% CI of 65 to 83 (figure 2).13,14,16-20,25,32-34,37,38,41-53 We found high inconsistency across the study results, with an I² value of 98.3%.

Assuming that all nonresponders had never experienced physical complaints, the overall percentage would be 22% (95% CI 16 - 30). Among the laparoscopic surgeons with MSDs, the rate of chronic pain ranged from 10.8% to 51.5% with an average of 27% (95% CI 7 - 54%).13,16,18,19,32,53 The remaining 9 reviewed studies did not report an overall MSD prevalence, but rather reported MSD prevalence rates for specific body parts.31,35,36,40,54-58 The body parts most commonly affected with discomfort or pain were the neck with 53% (95% CI 42 - 63),14,16-18,20,25,31-34,36,40,41,43,47,49,51,53,54,56,57 back with 51% (95% CI 34 - 68),14,17,18,25,36,43-45,47,49,51,53,54,56,58 shoulders with 51% (95% CI 41 - 60),14,17,18,20,31,32,34,36,43,44,47,49,51,53,55-57 and hands with 33% (95% CI 14 - 55)18,36,43,51,53,56. The inconsistency of the above-reported prevalence rates across studies was similar to that of the overall MSD prevalence.

Seven studies, including 1852 respondents, reported the prevalence of physical complaints related to robotic surgery.16,17,32,33,46,48,54 These studies reported a 56% (95% CI 32 - 78) overall prevalence of complaints associated with robotic surgery.16,17,32,33,48 Considering the defined time-frames in these studies, 52.8% of respondents reported ever experiencing physical discomfort,12,33,48 and 50.4% of surgeons reported complaints or discomfort during robotic surgery.16,17,32 Franasiak et al.32 and Plerhoples et al.,16 respectively, reported 11.9% and 5% rates of chronic or persistent strain due to robotic surgery. Robotic surgery was most commonly related to discomfort in the neck and in the hand/wrist region, including thumbs and fingers. On the basis of ergonomic considerations, respondents preferred the robotic operative modality compared with either open or laparoscopic surgery.32,54 and expressed that robotic surgery can be helpful for improving ergonomics.18,55 Accordingly, Plerhoples et al.16 reported that among MSD sufferers, 8.3% attribute their physical complaints to robotic surgery, 36.3% to open surgery and 55.4% to conventional laparoscopic surgery. Moreover, the difference in MSD prevalence is reportedly dependent on the body region.16,17,34,55 Another 3 studies specifically determined the overall percentages of physical complaints during or after open surgery, reporting rates of 56.5%, 65% and 85.4%.16,17,55 Among the 5 reviewed studies that reported prevalence numbers for both open and laparoscopic surgery, all showed a higher prevalence of complaints in laparoscopic surgery compared to open surgery.16,17,54-56
Four studies reported that a substantial number of respondents (range 16.6% to 34.8%) believed that their physical complaints affected their surgical performance or activity. \textsuperscript{31,41,44,55} Between 6.7% and 17% decreased their surgical practice (caseload) due to their physical complaints. \textsuperscript{18,31,34} Park et al. \textsuperscript{19} reported that 40% of respondents ignored their physical complaints during surgery. Szeto et al. \textsuperscript{34} found that 35.6% of respondents always worked through pain so that the quality of their surgical work would not suffer. Bagrodia and Raman \textsuperscript{54} and Plerhoples et al., \textsuperscript{16} respectively, reported that 25% and 30% of surgeons gave some consideration to their own physical discomfort when choosing an operative approach.

The reviewed studies reported several risk factors for MSD development. Sutton et al. \textsuperscript{52} specifically addressed sex as a risk factor, showing that female surgeons were significantly more likely to receive treatment for their hands and reported significantly more cases of shoulder discomfort, even with correction for glove size. Four other studies reported sex as a risk factor, showing that women were more likely to develop MSDs. \textsuperscript{18,31,48,51} Berguer and Hreljac \textsuperscript{62} specifically addressed the relationship between hand size and difficulty using instruments, finding that surgeons with a small glove size reported greater difficulty using all laparoscopic instruments compared to surgeons with a medium or large glove size. (P

---

**Figure 2** Overall MSD prevalence.

<table>
<thead>
<tr>
<th>Study</th>
<th>Events</th>
<th>Total</th>
<th>Proportion</th>
<th>95%-CI W(random)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berguer &amp; Hreljac (2004)</td>
<td>145</td>
<td>726</td>
<td>0.20</td>
<td>[0.17; 0.23]</td>
</tr>
<tr>
<td>Cass et al. (2014)</td>
<td>127</td>
<td>128</td>
<td>0.99</td>
<td>[0.96; 1.00]</td>
</tr>
<tr>
<td>Esposito et al. (2014)</td>
<td>8</td>
<td>14</td>
<td>0.57</td>
<td>[0.29; 0.82]</td>
</tr>
<tr>
<td>Filisetti et al. (2015)</td>
<td>62</td>
<td>138</td>
<td>0.45</td>
<td>[0.38; 0.54]</td>
</tr>
<tr>
<td>Fransasiak et al. (2012)</td>
<td>229</td>
<td>260</td>
<td>0.88</td>
<td>[0.84; 0.92]</td>
</tr>
<tr>
<td>Fransasiak et al. (2014)</td>
<td>19</td>
<td>42</td>
<td>0.45</td>
<td>[0.30; 0.61]</td>
</tr>
<tr>
<td>Giberti et al. (2014)</td>
<td>7</td>
<td>17</td>
<td>0.41</td>
<td>[0.18; 0.67]</td>
</tr>
<tr>
<td>Gofrit et al. (2008)</td>
<td>22</td>
<td>73</td>
<td>0.30</td>
<td>[0.20; 0.42]</td>
</tr>
<tr>
<td>Matern &amp; Koneczny (2007)</td>
<td>357</td>
<td>426</td>
<td>0.84</td>
<td>[0.80; 0.87]</td>
</tr>
<tr>
<td>McDonald et al. (2014)</td>
<td>214</td>
<td>350</td>
<td>0.51</td>
<td>[0.45; 0.57]</td>
</tr>
<tr>
<td>Miller et al. (2012)</td>
<td>61</td>
<td>61</td>
<td>1.00</td>
<td>[0.94; 1.00]</td>
</tr>
<tr>
<td>Morandea-Rivas et al. (2012)</td>
<td>63</td>
<td>78</td>
<td>0.81</td>
<td>[0.70; 0.92]</td>
</tr>
<tr>
<td>Park et al. (2010)</td>
<td>275</td>
<td>317</td>
<td>0.87</td>
<td>[0.83; 0.90]</td>
</tr>
<tr>
<td>Plerhoples et al. (2012)</td>
<td>833</td>
<td>1215</td>
<td>0.69</td>
<td>[0.66; 0.71]</td>
</tr>
<tr>
<td>Quinn &amp; Moohan (2015)</td>
<td>45</td>
<td>53</td>
<td>0.75</td>
<td>[0.72; 0.79]</td>
</tr>
<tr>
<td>Rubenburg et al. (2013)</td>
<td>288</td>
<td>396</td>
<td>0.73</td>
<td>[0.68; 0.77]</td>
</tr>
<tr>
<td>Santos-Carreras et al. (2012)</td>
<td>46</td>
<td>49</td>
<td>0.94</td>
<td>[0.83; 0.99]</td>
</tr>
<tr>
<td>Sari et al. (2010)</td>
<td>40</td>
<td>55</td>
<td>0.73</td>
<td>[0.59; 0.84]</td>
</tr>
<tr>
<td>Shepherd et al. (2016)</td>
<td>40</td>
<td>50</td>
<td>0.80</td>
<td>[0.66; 0.90]</td>
</tr>
<tr>
<td>Stomberg et al. (2010)</td>
<td>143</td>
<td>204</td>
<td>0.70</td>
<td>[0.65; 0.76]</td>
</tr>
<tr>
<td>Sutton et al. (2014)</td>
<td>272</td>
<td>314</td>
<td>0.87</td>
<td>[0.82; 0.90]</td>
</tr>
<tr>
<td>Szeto et al. (2009)</td>
<td>112</td>
<td>135</td>
<td>0.83</td>
<td>[0.76; 0.89]</td>
</tr>
<tr>
<td>Tjiam et al. (2014)</td>
<td>245</td>
<td>285</td>
<td>0.86</td>
<td>[0.81; 0.90]</td>
</tr>
<tr>
<td>Trejo et al. (2006)</td>
<td>25</td>
<td>38</td>
<td>0.66</td>
<td>[0.49; 0.80]</td>
</tr>
<tr>
<td>Van Veelen et al. (2003)</td>
<td>40</td>
<td>63</td>
<td>0.83</td>
<td>[0.50; 0.75]</td>
</tr>
<tr>
<td>Weuben et al. (2006)</td>
<td>250</td>
<td>284</td>
<td>0.88</td>
<td>[0.84; 0.92]</td>
</tr>
</tbody>
</table>

**Random effects model**

<table>
<thead>
<tr>
<th>Events</th>
<th>Proportion</th>
<th>95%-CI W(random)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5769</td>
<td>0.74</td>
<td>[0.65; 0.83]</td>
</tr>
</tbody>
</table>

**Prediction interval**

- 0.25
- 0.75
- 0.95
- 1

**Heterogeneity:** $I^2$-squared=98.3%, $tau^2$-squared=0.07, $P<0.0001$
Franasiak et al.\textsuperscript{18} found that increased pain symptoms were significantly associated with glove size; however, the majority of respondents in this study stated that their instruments fit ‘just right’ (70.8% to 84.8%, depending on type of instrument).

Overall, 12 studies examined the constraints of laparoscopic instruments.\textsuperscript{13,18-20,36,40,42,43,45,47,50,52} Three of these studies directly assessed the surgeons’ perspectives regarding handle design. Handle design was reported as a cause of physical complaints by 49% of respondents in the study of Sari et al.,\textsuperscript{20} 74.4% in Park et al.,\textsuperscript{19} and 83% in Matern and Koneczny.\textsuperscript{47} More specifically, Matern and Koneczny\textsuperscript{47} reported that 36% of surgeons complained about pressure areas, 26% about neuropraxia, and 57% about uncomfortable posture due to instruments. Cass et al.\textsuperscript{43} found that difficulty manipulating instruments was a significant causative factor in injury of disc prolapse. Moreover, improper positioning of the surgical setup—including monitor height and position, table height, and use of foot pedals—affected the surgeons’ comfort and was indicated as a risk factor for MSD development in 8 studies.\textsuperscript{13,14,19,20,36,40,47,52}

Eight studies assessed the workload in terms of caseload or number of hours spent performing MIS. The findings on this topic were somewhat ambiguous. Six studies reported that increased laparoscopic workload was significantly related to physical complaints.\textsuperscript{19,42,43,46,51,53} In contrast, McDonald et al.\textsuperscript{48} and Franasiak et al.\textsuperscript{18} identified no relationship between caseload and physical complaints for conventional laparoscopic procedures. However, the latter study reported that the number of cases per day and case length were significant risk factors for MSD development in robotic surgery. Plerhoples et al.\textsuperscript{16} found that surgeons with more laparoscopic cases ($P <0.0001$), greater annual laparoscopic volume ($P <0.0001$), or with longer career durations ($P =0.03$) were more likely to attribute their pain to the laparoscopic modality.

Ten studies reported data regarding experience and age. Four studies found that less experienced surgeons were more likely to report physical complaints.\textsuperscript{18,20,36,56} Accordingly, 4 studies reported that younger age was associated with higher rates of physical complaints.\textsuperscript{18,20,53,56} In contrast, Stomberg et al.\textsuperscript{51} and Cass et al.\textsuperscript{43} reported that injury risk increases with age. Plerhoples et al.\textsuperscript{16} identified no relationship between age or experience and physical complaints. McDonald et al.\textsuperscript{58} reported that younger surgeons were more likely to report symptoms; however, this association disappeared with correction for sex. Park et al.\textsuperscript{19} found that age and years of practice were not correlated with physical complaints. However, they identified a significant correlation between case volume and symptoms in the neck, right hand, upper extremities, and lower extremities (all $P <0.05$). They concluded that the number of cases performed per year was a stronger predictor of physical complaints than either age or years in practice.
Table 1 Results

<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
<th>Type of surgery</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adams et al.31</td>
<td>Sample: 7715 members of the AAGL and past attendees of the Surgical Film Festival</td>
<td>Benign, obstetric, and oncological surgery (27.5% of respondents were minimally invasive gynecological surgeons)</td>
<td>Self-composed questionnaire including a modified Standardized Nordic Musculoskeletal Questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 6.4% (495/7715)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bagrodia and Raman54</td>
<td>Sample: 1275 Urologists of the Endourologic Society and the Society of Urologic Oncology</td>
<td>Open, laparoscopic, and robot-assisted prostatectomy</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 8.3% (106/1275)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berguer and Hreljac42</td>
<td>Sample: 11,000 Laparoscopic surgeons members of SAGES, AAGL, and AWS</td>
<td>Laparoscopic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 6.7% (726/ 10835)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berguer et al.39,35</td>
<td>Sample: ~800 SAGES conference visitors</td>
<td>Laparoscopic surgery</td>
<td>Self-composed questionnaire (developed by SAGES Task Force on Ergonomics)</td>
</tr>
<tr>
<td></td>
<td>Response rate: 18.6% (149/800)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cass et al.43</td>
<td>Sample: 506 gynecologists (members of the British Society of Gynecological Endoscopy)</td>
<td>Laparoscopic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 25.3% (128/506)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery

Results

**Primary outcome:**

- 12-month prevalence of pain (daily pain)
  - Lower back: 75.6% (7.9%)
  - Neck pain: 72.9% (11.3%)
  - Shoulder pain: 66.6% (6.3%)
  - Upper back pain: 61.6% (6.9%)
  - Wrist/hand pain: 60.9% (7.1%)

**Other relevant outcomes:**

- 76.3–82.7% (depending on region) believed that performing surgery caused or worsened the pain
- 11.6% admitted they had decreased their surgical practice due to injury or pain
- 34.8% believed their surgical performance was affected by injury or pain
- Women show an approximately 2-fold higher risk of pain in the lower back, upper back, and hand/wrist region

**Primary outcome:**

- Prevalence of chronic back or neck pain: 43%

**Other relevant outcomes:**

- 50% of those who reported chronic pain said operating caused or exacerbated pain
- 25% of those who reported chronic pain said it impacted their choice of operative approach
- Neck and/or back pain was experienced in 50%, 56%, and 23% of surgeons after open, laparoscopic, and robot-assisted prostatectomy, respectively

**Primary outcome:**

- 20% (n=145) reported musculoskeletal problems

**Other relevant outcomes:**

- Subjects who reported musculoskeletal problems performed significantly greater proportions of laparoscopic procedures ($P < 0.01$)
- Respondents with small glove size had more difficulty using all laparoscopic instruments compared to the respondents with medium and large glove size ($P < 0.001$)

**Primary outcome:**

- Prevalence of pain/stiffness, further subdivided into
  - Neck pain: 52% (43% occasionally; 9% frequently)
  - Neck stiffness: 62% (44% occasionally; 18% frequently)
  - Shoulder/arm pain: 55% (43% occasionally; 12% frequently)
  - Shoulder/arm stiffness: 50% (39% occasionally; 11% frequently)
  - Hand/wrist pain: 47% (36% occasionally; 11% frequently)

**Primary outcome:**

- 99% (127/128) ever reported pain/stiffness directly attributable to laparoscopy, further subdivided into
  - Shoulder pain/stiffness: 80% (52% occasionally; 28% frequently)
  - Neck pain/stiffness: 74% (56% occasionally; 17% frequently)
  - Back pain/stiffness: 77% (54% occasionally; 22% frequently)
  - Hand pain/stiffness: 70% (56% occasionally; 14% frequently)

**Other relevant outcomes:**

- Vertebral disc prolapse was diagnosed in 15% (19/128) of respondents; 11 were located in the lumbar region and 32% (6/19) needed definitive treatment
- Injury of disc prolapse was significantly associated with hours worked per week ($P = 0.005$), years of laparoscopic practice ($P < 0.001$), more complex surgery ($P = 0.039$), and difficulty manipulating laparoscopic instruments ($P = 0.034$)
Table 1 Continued

<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
<th>Type of surgery</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esposito et al.55</td>
<td>Sample: 25 pediatric laparoscopists</td>
<td>Pediatric laparoscopic and open surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 92% (23/25)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Esposito et al.44</td>
<td>Sample: 14 pediatric laparoscopists</td>
<td>Conventional laparoscopy (CLS, n=7) and SILS (n=7)</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 100% (14/14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filisetti et al.45</td>
<td>Sample: unknown</td>
<td>Pediatric laparoscopic surgery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Response: 138</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Franasiak et al.18</td>
<td>Sample: 833 gynecologic oncologists (members of the SGO)</td>
<td>Open, laparoscopic, and robotic surgery</td>
<td>Self-composed Questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 31.2% (260/833)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Franasiak et al.32</td>
<td>Sample: robotic surgeons at the University of North Carolina (Ear Nose Throat, Urology, Obstetrics, and Gynecology)</td>
<td>Robotic</td>
<td>Modified version of the Nordic Musculoskeletal Questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 62.7% (42/67)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery

Results

Primary outcome:
78% (18/23) of surgeons that performed laparoscopy for more than 10 years reported shoulder symptoms;
61% (14/23) reported symptoms in the neck, elbow, and/or wrist (14/23)

Other relevant outcomes:
44% (8/18) of surgeons required painkillers at least twice a week
17% (3/18) reported that their pain influenced their surgical activity

Primary outcome:
57% (8/14) reported musculoskeletal disorders: 4 in SILS, 4 in CLS

Other relevant outcomes:
All musculoskeletal disorders after laparoscopy were located in the shoulder
75% (3/4) of musculoskeletal disorders after SILS were located in the shoulder and 25% (1/4) in the back
All SILS surgeons reported that SILS has bad ergonomics for surgeons compared with CLS
25% (2/8) reported that their pain influences their surgical activity: 1 in SILS, 1 in CLS

Primary outcome:
45% (62/138) reported musculoskeletal problems and 17 surgeons complained about >1 musculoskeletal problem
Overall, back pain was the main problem reported (18.1%; 25/138)

Primary outcome:
88% (216/244) of surgeons reported physical discomfort related to MIS, with 52% reporting persistent pain

Other relevant outcomes:
58.8% reported neck pain
54.0% reported back pain
53.6% reported shoulder pain
Shorter surgeons and surgeons with smaller glove size were more likely to experience strain ($P = 0.03$)
To decrease pain, surgeons changed positions (79%), limited their number of cases per day (14%), spread cases throughout the week (6%), or limited their total number of cases (3%)
29% had received treatment at any time for pain symptoms
16% of those with pain symptoms had received formal ergonomic training

Primary outcome:
45.2% (19/42) respondents reported strain specifically caused by robotic surgery (ever)

Additional results from the NMQ (12-month prevalence):
Neck: 74% (14/19)
Shoulders: 53% (10/19)
Lower back: 42% (8/19)
Wrist/hands 37% (7/19)

Other relevant outcomes:
Of those surgeons reporting strain, 26% (5/19) had persistent strain related to robotic surgery
Two surgeons had been prevented from performing normal daily activities from strain related to robotic surgery
Three surgeons reported seeking professional medical care for strain attributed to robotic surgery
Of those surgeons (N = 32) who received a 5-minute in-person ergonomic training program regarding console set-up instructions, 88% changed their practice. After this training, 74% of surgeons who reported strain, noted a decrease in strain
### Table 1 Continued

<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
<th>Type of surgery</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giberti et al.33</td>
<td>Sample: 39 robotic surgeons from Italian robotic centers</td>
<td>Robotic</td>
<td>Modified Standardized Nordic Musculoskeletal Questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 44% (17/39)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gofrit et al.46</td>
<td>Sample: Unknown Members of the Endourologic Society</td>
<td>Laparoscopy, hand-assisted laparoscopic surgery (HALS), and robotic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response: 73 endourologists</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemal et al.56</td>
<td>Sample: 350 urologists</td>
<td>Laparoscopic and open surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 58.3% (204/350)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johnston et al.57</td>
<td>Sample: 42 laparoscopic program directors</td>
<td>Laparoscopy, hand-assisted laparoscopic surgery (HALS)</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 60% (25/42) urologists</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaya et al.40</td>
<td>Sample: 100 OR personnel, including anesthesiologists and surgery nurses</td>
<td>Laparoscopy</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 82% (82/100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liang et al.36</td>
<td>Sample: 300 urologic surgeons in China</td>
<td>Laparoscopy</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 80.3% (241/300)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1

Continued

<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
<th>Type of surgery</th>
<th>Tool</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giberti et al.</td>
<td>Sample: 39 robotic surgeons from Italian robotic centers</td>
<td>Robotic</td>
<td>Modified Standardized Nordic Musculoskeletal Questionnaire</td>
<td>Primary outcome: 41% (7/17) reported recurrent musculoskeletal pain that started at the first use of the robot Other relevant outcomes: 35% (6/17) reported feeling pain during their daily surgical activities 29% (5/17) reported pain in the cervical spine 23.5% (4/17) reported pain in the upper limbs</td>
</tr>
<tr>
<td>Gofrit et al.</td>
<td>Sample: Unknown Members of the Endourologic Society</td>
<td>Laparoscopy, hand-assisted laparoscopic surgery (HALS), and robotic surgery</td>
<td>Self-composed questionnaire</td>
<td>Primary outcome: 30% (22/73) reported neuromuscular or arthritic symptoms during surgery Other relevant outcomes: 18% (13/73) reported paresthesias, most commonly in the thumb and/or middle finger HALS was most associated with symptoms, and robotic surgery was least associated with symptoms The total number of laparoscopic procedures performed by the responder was significantly positively correlated with the risk of sustaining an injury</td>
</tr>
<tr>
<td>Hemal et al.</td>
<td>Sample: 350 urologists</td>
<td>Laparoscopic and open surgery</td>
<td>Self-composed questionnaire</td>
<td>Primary outcome: prevalence of pain and stiffness in laparoscopic and open surgery, further subdivided into Frequent neck pain in laparoscopy and open surgery: 13% and 6%, respectively. Frequent shoulder stiffness in laparoscopy and open surgery: 18% and 10%, respectively. Frequent finger numbness in laparoscopic and open surgery: 18% and 2.8%, respectively Other relevant outcomes: The frequency of finger numbness and eye strain was significantly higher in laparoscopic surgeons compared with open surgery (P = 0.004)</td>
</tr>
<tr>
<td>Johnston et al.</td>
<td>Sample: 42 laparoscopic program directors</td>
<td>Laparoscopy, hand-assisted laparoscopic surgery (HALS)</td>
<td>Self-composed questionnaire</td>
<td>Primary outcome: There were significantly more hand/wrist, forearm, and shoulder pain/injuries associated with HALS (P &lt; 0.004). Hand-assisted laparoscopy is associated with more frequent neuromuscular strain to the upper extremity than standard laparoscopy, but surgeons performing standard laparoscopy experience more neck pain or injury. Other relevant outcomes: 33% of HALS versus 8% of Laparoscopy led to hand/wrist pain ‘usually/frequently’ 25% of HALS versus 10% Laparoscopy led to forearm/shoulder pain ‘usually/frequently’ 85% of Hals versus 60% Laparoscopy surgeons experience rarely or never neck pain 65% of HALS versus 66% Laparoscopy surgeons experience rarely or never back pain</td>
</tr>
<tr>
<td>Kaya et al.</td>
<td>Sample: 100 OR personnel, including anesthesiologists and surgery nurses</td>
<td>Laparoscopy</td>
<td>Self-composed questionnaire</td>
<td>Primary outcome: 72% had neck pain and 70% back pain during laparoscopic surgery Other relevant outcomes: 68% reported discomfort due to self-reported static body posture 44% reported tremors resulting from instrument manipulation 41% of surgeons and 47% of residents reported discomfort owing to continuous foot flexion during foot pedal manipulation</td>
</tr>
<tr>
<td>Liang et al.</td>
<td>Sample: 300 urologic surgeons in China</td>
<td>Laparoscopy</td>
<td>Self-composed questionnaire</td>
<td>Primary outcome: prevalence of musculoskeletal symptoms/discomfort, further subdivided into neck (58%), back (53%), shoulder (34%), wrist (33%), hand (30%), and leg (22%) Other relevant outcomes: Surgeons who had performed &lt; 250 surgeries experienced more discomfort than those with &gt; 250 surgeries in their hands (P = 0.029), wrists (P = 0.022), and back (P = 0.026) Most of the respondents (84.6%) were unaware of the ergonomic guidelines</td>
</tr>
<tr>
<td>Author</td>
<td>Study population, sample size, and response rate</td>
<td>Type of surgery</td>
<td>Tool</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| Matern and Koneczny47 | Sample: 3621 surgeons working in Germany  
Response rate: 11.7% (425/3621)                                                                                   | Laparoscopic and open surgery                        | Self-composed questionnaire               |
| McDonald et al.48    | Sample: 1279 gynecologic oncologists (members of the SGO)  
Response rate: 27.4% (350/1279)                                                                              | Open, laparoscopic, and robotic surgery              | Self-composed questionnaire               |
| Miller et al.25      | Sample: Unknown  
Respondents: 61 laparoscopic surgeons in the central Texas area                                                | Laparoscopy                                          | Modified survey based on the SAGES Task Force on Ergonomics Questionnaire and the Safety Attitudes Questionnaire (SAQ) |
| Morandeira-Rivas et al 37 | Sample: 262 surgeons  
Response rate: 29.8% (78/262)                                                                                   | SILS                                                 | Questionnaire elaborated by the ergonomics subcommittee of the SAGES |
Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery

Table 1

<table>
<thead>
<tr>
<th>Author Study population, sample size, and response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of surgery Tool</td>
</tr>
<tr>
<td>Matern and Koneczny47 Sample: 3621 surgeons working in Germany Response rate: 11.7% (425/3621)</td>
</tr>
<tr>
<td>Laparoscopic and open surgery</td>
</tr>
<tr>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td>Other relevant outcomes:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>McDonald et al.48 Sample: 1279 gynecologic oncologists (members of the SGO) Response rate: 27.4% (350/1279)</td>
</tr>
<tr>
<td>Open, laparoscopic, and robotic surgery</td>
</tr>
<tr>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Miller et al.25 Sample: Unknown</td>
</tr>
<tr>
<td>Respondents: 61 laparoscopic surgeons in the central Texas area</td>
</tr>
<tr>
<td>Laparoscopy Modified survey based on the SAGES Task Force on Ergonomics Questionnaire and the Safety Attitudes Questionnaire (SAQ)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Morandeira-Rivas et al.37 Sample: 262 surgeons Response rate: 29.8% (78/262)</td>
</tr>
<tr>
<td>SILS Questionnaire elaborated by the ergonomics subcommittee of the SAGES</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Other relevant outcomes:</td>
</tr>
<tr>
<td>Author</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Park et al.19</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Plerhoples et al.16</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Quinn and Moohan49</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Ruitenburg et al.41</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery

### Results

**Primary outcome:**
86.9% (272/317) reported physical symptoms or discomfort

**Other relevant outcomes:**
- The strongest predictor of symptoms was high case volume—except for eye and back symptoms, which were consistently reported even with low case volumes
- Other injuries or conditions reported: carpal tunnel syndrome (n=4), disc problems (n=4), headache (n=3), tennis elbow (n=2), and shoulder muscle spasm (n=2)
- Women reported more arm symptoms, and men reported more lower extremity problems

**Primary outcome:**
69% (834/1215) reported physical discomfort or symptoms attributable to operating, further subdivided into
- Neck: 35.2% in robotic surgery, 44.1% in laparoscopic surgery, 46.6% in open surgery
- Upper back: 21.0% in robotic surgery, 41.4% in laparoscopic surgery, 39% in open surgery
- Right shoulder: 7.9% in robotic surgery, 33.2% in laparoscopic surgery, 12.3% in open surgery
- Lower back: 18.9% in robotic surgery, 44.5% in laparoscopic surgery, 51.8% in open surgery

**Other relevant outcomes:**
- 70% reported pain while performing laparoscopic surgery, compared to 36% for robotic, and 65% for open surgery ($P < 0.0001$)
- 30% of surgeons said they give at least some consideration to their own physical discomfort when choosing an operative modality
- Persistent or chronic pain: 5% in robotic surgery, 19% in laparoscopic surgery, and 17% in open surgery ($P < 0.0001$)
- 99 of 214 surgeons (8%) reported an injury requiring treatment due to laparoscopic surgery, 76 (6%) due to open surgery, and 30 (3%) due to robotic surgery

**Primary outcome:**
84.9% (45/53) of trainees reported pain during laparoscopic surgery, further subdivided into
- Neck: 42%
- Back: 72%
- Shoulder: 43%
- Leg: 37%

**Other relevant outcomes:**
- Two trainees had required sick leave as a result of pain, while 1 trainee had sought medical attention.
- Seventeen trainees had received treatment (analgesia, physiotherapy or alternative) for their symptoms

**Primary outcome:**
41% (37/91) of surgeons found their work physically strenuous versus 13% (35/280) of other physicians ($P < 0.000$)

**Other relevant outcomes:**
- Both groups reported that most of their physical complaints were in their neck (39 and 32%, and 17% vs 15% found this to be work-impairing) and arm regions (36 and 27%, 42% vs 26% found this work-impairing)
- Compared with hospital physicians, significantly more surgeons (56 vs 14%, respectively) indicated that their work contributed to physical complaints in the leg region.
- 14% of surgeons and 21% of other hospital physicians experienced difficulties at work because of impairments in their physical well-being
### Table 1 Continued

<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
<th>Type of surgery</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santos-Carreras et al.17</td>
<td>Sample: 250 surgeons</td>
<td>Open, laparoscopic, and robotic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 19.6% (49/250)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sari et al.20</td>
<td>Sample: 92 laparoscopic surgeons and surgical trainees (gynecologists, general surgeons, and urologists)</td>
<td>Laparoscopic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 60% (55/92)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shepherd et al.50</td>
<td>Sample: Unknown</td>
<td>Laparoscopic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Respondents: 50 surgeons and trainees in Southeast England</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stomberg et al.51</td>
<td>Sample: 558 general surgeons and gynecologists</td>
<td>Laparoscopic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 68% (378/558); 204 performed both laparoscopy and laparotomy and were analyzed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sutton et al.52</td>
<td>Sample: 2000 members of the SAGES</td>
<td>Laparoscopic surgery</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 15.7% (314/2000)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery

Results

**Primary outcome:**
main body areas of complaints during surgery, further subdivided into
Back: 52% in open surgery, 35% in laparoscopic surgery, 20% in robotic surgery
Neck: 52% in open surgery, 38% in laparoscopic surgery, 28% in robotic surgery

**Other relevant outcomes:**
Finger discomfort was experienced by 28% during laparoscopic surgery

**Primary outcomes:**
73% (40 of 55) reported physical complaints during or after laparoscopic procedures

**Other relevant outcomes:**
The most frequently affected body areas were shoulders (45%), low back (26%), and neck (15%)
Among surgeons with less experience (<50 procedures), 12 (86%) surgeons had physical complaints, whereas 28 (68%) surgeons in the more experienced group reported complaints ($P = 0.011$)

**Primary outcome:**
symptoms were reported in at least one body region by 76% during short cases and 81% during long cases.

**Other relevant outcomes:**
41% of respondents reported moderate or severe discomfort due to the use of laparoscopic instruments
Female sex and those with a smaller glove size or fewer years of experience were more likely to report symptoms related to instrument handle dimensions
69% of respondents believed ergonomics should be incorporated into courses

**Primary outcome:**
More than 70% of the laparoscopists had one or more physical symptoms/pain, further subdivided into
Lower back: 55% of gynecologists versus 48% of general surgeons
Neck: 50% of gynecologists versus 44% of general surgeons
Shoulder: 52% of gynecologists versus 37% of general surgeons

**Other relevant outcomes:**
Pain was the most common symptom, followed by fatigue and stiffness
Longer work experience and ageing were associated with significantly more disorders ($P < 0.01$)
Female physicians had significantly more symptoms in the neck, shoulders, wrists, upper-back, and head ($P < 0.01$)

**Primary outcome:**
86.5% of women reporting attributed physical discomfort to laparoscopic surgery, which was comparable to men
Operating, further subdivided into
discomfort in lower body (hips, knees, ankles, and feet): 20% (11/54) of females versus 35% (91/261) of males
discomfort of shoulder area (neck, shoulder, and upper back): 77% of females versus 27% of males
discomfort in neck: 62% of females versus 18% of males

**Other relevant outcomes:**
Female surgeons were more likely to receive treatment for their hands, including the wrist, thumb, and fingers (odds ratio [OR] 3.5, $P = 0.028$).
Women with a larger glove size (7–8.5) reported more cases of treatment for their hands than men with the same glove size (21% versus 3%, $P = 0.016$)
Women who wore a size 5.5–6.5 surgical glove reported significantly more cases of discomfort in their shoulder area (neck, shoulder, and upper back) than men who wore the same size surgical glove (77% vs 27%, $P = 0.004$)
<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
<th>Type of surgery</th>
<th>Tool</th>
</tr>
</thead>
</table>
| Szeto et al.34  | Sample: 500 general surgeons working in general surgery departments in public hospitals in Hong Kong  
Response rate: 27% (135/500) | Open, laparoscopic, endovascular, and endourology surgery  
Self-composed questionnaire including a modified Standardized Nordic Musculoskeletal Questionnaire and a modified workstyle short form |                                                                    |
| Tjiam et al.53  | Sample: unknown  
Respondents: 285 urologists from different countries (mainly Europe) performing endourology and laparoscopy | Laparoscopy and endourology  
Self-composed questionnaire |                                                                    |
| Trejo et al.38  | Sample: unknown  
Respondents: 38 laparoscopic surgeons from all over the US (all attendants of the advanced laparoscopic training courses at the University of Nebraska Medical Center) | Laparoscopic surgery  
Self-composed questionnaire |                                                                    |
| Van Veelen et al.13 | Sample: 80  
Including surgeons, residents, anesthesiologists, anesthesiologist assistants, surgical nurses  
Response rate: 79% (63/80) | Laparoscopy, arthroscopy, and angioscopy  
Observation, self-composed questionnaire |                                                                    |
### Results

**Primary outcome:**
Over 80% of the respondents reported musculoskeletal symptoms in at least one area within the past 12 months, further subdivided into:
- Neck: 82.9%
- Low back: 68.1%
- Shoulder: 57.8%
- Upper back: 52.6%

**Other relevant outcomes:**
- 88.9% of respondents perceived sustained static and/or awkward posture as the factor most commonly associated with neck symptoms
- 35.6% of respondents reported “working through pain so that the quality of their work would not suffer”
- Medical treatment: 7% for neck pain, 8% for lower back pain, 7% for upper back pain, 2% for shoulder pain
- Medication use: 14% for neck pain, 2% for lower back pain, 6% for upper back pain, 5% for shoulder pain

<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Szeto et al.</td>
<td>Sample: 500 general surgeons working in general surgery departments in public hospitals in Hong Kong. Response rate: 27% (135/500)</td>
</tr>
<tr>
<td>Tjiam et al.</td>
<td>Sample: Unknown. Respondents: 285 urologists from different countries (mainly Europe) performing endourology and laparoscopy.</td>
</tr>
<tr>
<td>Trejo et al.</td>
<td>Sample: Unknown. Respondents: 38 laparoscopic surgeons from all over the US (all attendants of the advanced laparoscopic training courses at the University of Nebraska Medical Center).</td>
</tr>
<tr>
<td>Van Veelen et al.</td>
<td>Sample: 80 including surgeons, residents, anesthesiologists, anesthesiologist assistants, surgical nurses. Response rate: 79% (63/80)</td>
</tr>
</tbody>
</table>

**Primary outcome:**
86.0% (245/285) experienced musculoskeletal complaints within the past 12 months, further subdivided into:
- Neck: 59.3% (30.5% mild, 18.9% moderate, 8.8% serious, 1.1% severe)
- Back: 56.9% (22.8% mild, 23.5% moderate, 8.8% serious, 1.8% severe)
- Shoulder: 51.2% (22.1% mild, 18.9% moderate, 9.1% serious, 1.1% severe)
- Arm: 26% (13.7% mild, 9.8% moderate, 2.5% serious, 0% severe)
- Wrist: 20.8% (11.6% mild, 6.7% moderate, 2.1% serious, 0.4% severe)
- Hand: 21.4% (14.0% mild, 4.6% moderate, 2.1% serious, 0.7% severe)

**Other relevant outcomes:**
- 49% of the urologists experienced chronic musculoskeletal complaints, with significant risk factors including endourology (odds ratio [OR] 3.06; 95% confidence interval [CI] 1.37–6.80) and laparoscopy (OR 1.70; 95% CI 1.27–2.28)

**Primary outcome:**
66% (25/38) experienced problems using the conventional grasper, with 29% of surgeons reporting numbness of the fingers or thumb after surgery with conventional laparoscopic tools

**Other relevant outcomes:**
- Pain (stiffness) in other body areas, further subdivided into:
  - Neck: 65% (62%)
  - Shoulder/arm: 48% (58%)
  - Hand/wrist: 55% (48%)
  - Back: 50% (52%)

**Primary outcome:**
63% (40/63) experienced physical discomfort during the surgical procedure

**Other relevant outcomes:**
- The surgeons and residents reported that manipulating endoscopic products caused discomfort in the head, shoulders, neck, arms, back, and hands
- The main causes were the positioning of apparatus and staff, work clothing, and the limited reach of apparatus and/or instruments
- The lead apron caused discomfort in the neck, shoulders, and back (surgeons/residents 42%, anesthesiologists/assistants 36%, surgical nurses 49%)
### Table 1 Continued

<table>
<thead>
<tr>
<th>Author</th>
<th>Study population, sample size, and response rate</th>
<th>Type of surgery</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wauben et al.</td>
<td>Sample: 1292 surgeons and residents, working mainly in Europe, performing laparoscopic and/or thoracoscopic procedures within the digestive, thoracic, urologic, gynecologic, and pediatric disciplines</td>
<td>Laparoscopy and thoracoscopy</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Response rate: 22% (284/1292)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wolf Jr et al.</td>
<td>Sample: unknown (18 academic centres in the United States)</td>
<td>Laparoscopy</td>
<td>Self-composed questionnaire</td>
</tr>
<tr>
<td></td>
<td>Respondents: 18 urologists (from 15 different centres)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results

Primary outcome: 
Physical discomfort during laparoscopy, further subdivided into
  Neck pain: 78%
  Shoulder pain: 77%
  Back pain: 77%

Other relevant outcomes:
  88% experienced muscle fatigue due to static posture
  64% agreed with the proposition that a bad table height causes discomfort in the neck
  77% agreed with the proposition that a bad table height causes discomfort in the shoulders
  70% agreed with the proposition that monitor height causes discomfort in the neck
  76% agreed with the proposition that monitor position causes discomfort in the neck
  57% agreed with the proposition that foot pedals cause discomfort in the foot
  89% were unaware of ergonomic guidelines, although 100% stated that they find ergonomics important

Primary outcome:
  28% and 17% reported frequent neck and shoulder pain, respectively, in association with laparoscopy

Other relevant outcomes:
  Occasional pain was experienced by 67% in the wrists, 33% in the back, and 11% in the elbow
  To alleviate strain, 61% lowered the table, and 39% altered the manner in which instruments are held
  Two surgeons obtained professional consultation for their injuries
Discussion

Our present systematic review was designed to evaluate the available literature regarding physical complaints and MSDs among surgeons performing laparoscopy. We found high inconsistency across studies, along with a low overall response rate. MSD prevalence among surgeons was found to be 74% (95% CI 65 - 83). However, if all nonresponders were assumed to have never experienced MSDs, this prevalence was adjusted to 22% (95% CI 16 - 30).

Despite early reports of the physical drawbacks of laparoscopic surgery in the late 1990s, little has improved regarding the ergonomics and physical workload for surgeons. This may be partly because the laparoscopic approach has become the preferred approach from the patients' perspective. Furthermore, there has been clear development of greater surgical specialization. Consequently, subgroups of surgeons may spend a relatively high percentage of their daily activities performing laparoscopic procedures. Another issue is that a higher surgical caseload might actually be beneficial for several patient-reported outcome measures. Altogether, these trends in the field have led to an overall rising caseload of laparoscopic procedures, with a correspondingly higher chance of surgeons developing MSDs.

One might consider physical complaints to be a “part of the job”. However, when such complaints appear to negatively influence the quality of surgical care, it becomes a matter of professional ethics. Several reviewed studies described surgeons who believed that their surgical performance was negatively affected by their own injury or pain. In 2 studies, respondents expressed that their physical complaints influenced their choice of operative approach. This suggests that in some cases patients may not receive the best clinical care available due to their surgeon's physical condition. Szeto et al. found that 35.6% of respondents reported almost always “working through pain so that the quality of their work would not suffer”. However, it remains unclear whether physical complaints really impact surgical outcomes. Especially in cases of laparoscopic hysterectomy or (hemi) colectomy—where important steps are taken late in the procedure—the physiological process underlying fatigue of the surgeon’s upper extremity may play a role in complaint occurrence. Sari et al. found that no respondents reported any surgical complications due to their own fatigue or physical complaints; however, this could have been influenced by surgeons’ reluctance to admit to such occurrences.

There remains a need for further clarification of the difference in physical complaints between the sexes. On average, female surgeons have smaller hands and glove size. Almost all laparoscopic instruments have a “one size fits all” handle, and previous studies report that such handles are less comfortable for surgeons with small glove sizes. This could partially explain the higher rates of physical complaints in the upper extremity.
among women. This finding could also be influenced by anatomical muscular differences between the sexes. Moreover, differences in interplay between working life and private circumstances may be of influence. Furthermore, it is possible that male surgeons are less aware of their complaints or more reluctant to admit that they experience physical complaints. The fact that less-experienced surgeons report more complaints justifies an enhanced focus on ergonomics during surgical residency. Junior surgeons are less familiar with laparoscopic procedures and may intrinsically experience higher mental and physical stress levels. Consequently, their main intraoperative focus will be on the surgical procedure, with less attention paid to their own physical status, surgical setup, or other ergonomic conditions. Implementing an ergonomic module for surgical residents will likely enhance their awareness of surgical conditions as a whole.

One reported benefit of the implementation of robotic surgery is that it offers superior ergonomics. However, our present review showed that sitting in the console still has its limitations, which is supported by evidence in several prior studies. Among robotic surgeons, MSD prevalence is the highest in the neck, with up to 35% of robotic surgeons experiencing pain, stiffness, or numbness in this area. Studies in pathologists and cytotechnologists demonstrate that prolonged use of conventional microscopes is a risk factor for developing (chronic) musculoskeletal injuries, including shoulder, neck, back pain, and fatigue. Robotic surgery involves a similar body posture as working with a microscope. Thus, robotic surgeons may benefit from existing knowledge regarding ergonomic guidelines for prolonged microscope use.

This review has several potential limitations. First, the studies used different questionnaires and definitions of MSDs. The common use of terms, such as physical complaints, fatigue, numbness, and pain, contributed to overall inconsistency among studies. The appropriateness of pooling results obtained from various more-or-less self-composed questionnaires is scientifically debatable. However, this was regarded as the least objectionable option available for use in our present review. Furthermore, the STROBE score is not a formal tool for measuring methodological study quality, but was used in our study as a checklist for reporting several outcomes and biases. Another limitation is the possibility of recall bias. All reviewed studies were retrospective analyses, and it is possible that not all respondents were able to clearly report their physical condition. There is also a potential for selection bias, in that the respondents who had experienced physical complaints may have been more eager to complete a questionnaire on this topic. Consequently, the percentage of surgeons reporting physical complaints may be an over-representation within the whole population of laparoscopic surgeons. It is known that survey studies among physicians are prone to low response rates. However, it is possible that those surgeons who did not experience physical complaints were reluctant to respond to the questionnaires. Therefore, we recalculated the overall prevalence rate in
case the nonresponders had never experienced physical complaints. Moreover, not all studies reported whether the surgeons were asked for their opinion on whether their physical complaints were more or less directly related to MIS. Future prospective studies must focus on the distinction between any MSD versus clinically relevant MSDs with regards to patient safety.

In conclusion, the findings of this systematic review indicate that the MSD prevalence among surgeons performing MIS is likely higher than is commonly acknowledged, warranting future well-designed studies. This matter is clinically relevant, since kinesiology studies reveal that fatigue and MSDs can impact psychomotor performance. Alongside epidemiological research, future studies should also focus on evaluating surgical tasks, environment, and instrument design. Interventions, such as formal ergonomic training, warm-up before surgery, and microbreaks during surgery, may improve surgeons’ physical health and warrant further scientific evaluation.
Appendix 1 Search Strategies

**Pubmed**

**Embase**
- 1. ergonomics/
- 2. ergonom*[ti,ab.
- 3. human factors research/
- 4. human factors.ti,ab.
- 5. occupational health/
- 6. occupational health.ti,ab.
- 7. workload/
- 8. workload.ti,ab.
- 9. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
- 10. minimally invasive surgery/
- 11. (minimal* and invasive and surg*).ti,ab.
- 12. minimal access surg*.ti,ab.
- 13. laparoscopic surgery/
- 14. laparoscop*[ti,ab.
- 15. endoscopic surgery/
- 16. endoscop*[ti,ab.
- 17. computer assisted surgery/
- 18. computer assisted surg*.ti,ab.
- 19. robotics/
- 20. (robot* and surg*).ti,ab.
- 21. 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20
- 22. 9 and 21

**Cochrane**
- #1 MeSH descriptor: [Human Engineering] explode all trees
- #2 Human Engineering:ti,ab,kw (Word variations have been searched)
- #3 ergonom*[ti,ab,kw (Word variations have been searched)
- #4 “human factors*”.ti,ab,kw (Word variations have been searched)
- #5 MeSH descriptor: [Occupational Health] this term only
Chapter 3

#6 occupational health:ti,ab,kw (Word variations have been searched)
#7 MeSH descriptor: [Workload] this term only
#8 workload:ti,ab,kw (Word variations have been searched)
#9 #1 or #2 or #3 or #4 or #5 or #6 or #7 or #8
#10 MeSH descriptor: [Surgical Procedures, Minimally Invasive] this term only
#11 (minimal* and invasive and surg*):ti,ab,kw
#12 minimal access surg*:ti,ab,kw (Word variations have been searched)
#13 MeSH descriptor: [Endoscopy] this term only
#14 endoscop*:ti,ab,kw (Word variations have been searched)
#15 MeSH descriptor: [Laparoscopy] explode all trees
#16 laparoscop*:ti,ab,kw (Word variations have been searched)
#17 MeSH descriptor: [Surgery, Computer-Assisted] this term only
#18 computer-assisted surger*:ti,ab,kw (Word variations have been searched)
#19 MeSH descriptor: [Robotics] this term only
#20 robot* and surg*:ti,ab,kw (Word variations have been searched)
#21 #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20
#22 #9 and #21

Cinahl

S1 (MH “Ergonomics+”)
S2 TI Ergonom* OR AB Ergonom*
S3 TI “human factors” OR AB “human factors”
S4 (MH “Occupational Health+”)
S5 TI “occupational health” OR AB “occupational health”
S6 (MH “Workload”)
S7 TI workload OR AB workload
S8 S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7
S9 TI minimal* OR AB minimal*
S10 TI invasive OR AB invasive
S11 TI surg* OR AB surg*
S12 S9 AND S10 AND S11
S13 TI “minimal access surg**” OR AB “minimal access surg**”
S14 (MH “Surgery, Laparoscopic+”)
S15 TI laparoscop* OR AB laparoscop*
S16 (MH “Endoscopy”)
S17 TI endoscop* OR AB endoscop*
S18 (MH “Surgery, Computer-Assisted”)
S19 TI “computer assisted surg**” OR AB “computer assisted surg**”
S20 (MH “Robotics”)
S21 TI robot* OR AB robot*

———
64
Prevalence of musculoskeletal disorders among surgeons performing minimally invasive surgery

S22 TI surg* OR AB surg*
S23 S21 AND S22
S24 (MH "Minimally Invasive Procedures")
S25 S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S23 OR S24
S26 S8 AND S25

Web of Science
#1 TOPIC: (ergonom*)
#2 TOPIC: ("human factors")
#3 TOPIC: ("occupational health")
#4 TOPIC: (workload)
#5 #4 OR #3 OR #2 OR #1
#6 TOPIC: (minimal*) AND TOPIC: (invasive) AND TOPIC: (surg*)
#7 TOPIC: ("minimal access surg")
#8 TOPIC: (laparoscop*)
#9 TOPIC: (endoscop*)
#10 TOPIC: ("computer assisted surg")
#11 TOPIC: (robot*) AND TOPIC: (surg*)
#12 #11 OR #10 OR #9 OR #8 OR #7 OR #6
#13 #12 AND #5

PsychINFO
1. human factors engineering/
2. ergonom*,ti,ab
3. human factors,ti,ab.
4. occupational health/
5. occupational health,ti,ab.
6. work load/
7. workload,ti,ab.
8. 1 or 2 or 3 or 4 or 5 or 6 or 7
9. (minimal* and invasive and surg*),ti,ab.
10. minimal access surg*,ti,ab.
11. laparoscop*,ti,ab.
12. endoscop*,ti,ab.
13. surgery/
14. computer assisted surg*,ti,ab.
15. robotics/
16. (robot* and surg*),ti,ab.
17. 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16
18. 8 and 17
References


The physical workload of surgeons: a comparison of SILS and conventional laparoscopy

Chantal C.J. Alleblas
Simone Velthuis
Theodoor E. Nieboer
Colin Sietses
Dick F. Stegeman

Surgical Innovation 2015;22(4):376-381
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 the 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 the 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 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 to 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 movement19,20 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 conventional laparoscopy 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 tasks24,25 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 hypothesized that the further restricted mobility and the counterintuitive control of instruments in SILS lead to an increase of 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, The 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 randomized between the participants. The order of tasks was not randomized to standardize 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 two graspers (task 1; Figure 2b). The third task involved a suture trail which had to be completed with one grasper and one 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. In between the series, the participants were given 5 minutes of rest. Prior to the experiment, the participants had the opportunity to familiarize themselves with the tasks by practicing it for a fixed time of 1 minute for task one, 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.

Data collection
With a 16-channel portable electromyography (EMG) acquisitions system (Porti, TMSi, Enschede, The 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. 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 digitalized with a sample rate of 2000 samples/s (LabVIEW, National Instruments Corp, Austin, TX, USA).
Figure 1 Laparoscopic box training system (www.lapstar.nl).

Figure 2 Tasks: ‘walking’ a textile strap (a), coin replacement (b), and the suture trial (c).
To record the posture and movement of the participants, a camera (Kodak Playsport Zx5, NY, USA) 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 (RSME) 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 (RPE) CR10 scale was used to compare intensity level 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 analyzed by means of written protocols in MATLAB 2010 (The Mathworks, Inc., Natick MA, USA). The first 10 seconds 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 500ms.

<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>
The average RMS amplitudes were calculated. Because this study involved paired observations, all initial values associated with CLS were used to normalize the data. The values associated with SILS were converted to a percentage of the initial CLS values. The equation below expresses the normalized average RMS amplitude for SILS for each individual muscle in percentage difference from the CLS value.

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

**Statistics**

Statistical analysis was carried out using SPSS 20 (SPSS, Inc., Chicago Ill, USA). Average RMS amplitudes were analyzed by using a 2 x 3 (surgical technique x task) repeated-measures ANOVA. Bonferroni adjustment was used in the pairwise comparisons of the main effects for surgical technique and tasks. Scores on the RSME and Borg RPE scale were analyzed by means of a one-way repeated-measures ANOVA. A \( P \) value of <.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 mm. pollicis brevis had to be excluded.

**Table 2** Participants descriptive summarya.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>SILS</th>
<th>CLS</th>
<th>Other surgery</th>
<th>Experience*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(years)</td>
<td>(hours/week)</td>
<td>(hours/week)</td>
<td>(hours/week)</td>
<td>(years)</td>
</tr>
<tr>
<td>Surgeons (n=6)</td>
<td>44.8</td>
<td>3.2</td>
<td>9.0</td>
<td>11.2</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td>[33-52]</td>
<td>[0-8]</td>
<td>[4-16]</td>
<td>[6-20]</td>
<td>[2-21]</td>
</tr>
<tr>
<td>Surgical residents (n=4)</td>
<td>31.3</td>
<td>0.8</td>
<td>9.5</td>
<td>8.5</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>[28-33]</td>
<td>[0-2]</td>
<td>[2-14]</td>
<td>[8-10]</td>
<td>[1.5-6]</td>
</tr>
</tbody>
</table>

Abbreviations: SILS, single-incision laparoscopic surgery; CLS, conventional laparoscopic surgery

a Numbers are expressed as mean [range].

* Defined as years of being consultant in surgeons and years of training in 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 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 (\(P < .01\)). 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 to task 2 (\(P < .05\)), 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 to task 1 (\(P < .05\)).

<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)</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>.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>.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>.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>.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>.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>.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>.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>.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>.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>.347</td>
</tr>
<tr>
<td>m. extensor carpi radialis</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>.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>.715</td>
</tr>
<tr>
<td>m. flexor carpi ulnaris longus</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>.971</td>
</tr>
<tr>
<td></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>.336</td>
</tr>
</tbody>
</table>

* Data presented as mean ± standard deviation. Positive differences indicate higher muscle activity in SILS, whereas negative differences indicate higher muscle activity in CLS.

\(P = p\)-value; Boldfaced results indicate significant differences (\(P < 0.05\)).
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; \( P = .703 \)) or in the ratings of perceived exertion (baseline: 1.9 ± 1.2; CLS: 2.2 ± 1.1; SILS: 2.1 ± 1.0; \( P = .327 \)). 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 to open surgery.\(^2^0\) In addition, physical discomfort and fatigue are frequently reported after laparoscopic operations.\(^1^0-\)\(^1^3\) Where many studies draw a line between open, laparoscopic, and robotic surgery, this study provides additional information according to 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.\(^3^0\) 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 to CLS.\(^3^0\)

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 back, neck and shoulders as a consequence of minimally invasive surgery.\(^1^0-\)\(^1^3\) In contrast, participants in this study primarily report 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 was 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 low level muscle activation is the continuous activation of low threshold, less fatigable, small (type I) motor units. Therefore, the risk of fatigue is of particular concern on the long term regarding deterioration at the central level, which eventually may well affect the coordination of movements. 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. This may partly explain the finding by Trastulli et al. in their meta-analysis of SILS versus CLS in cholecystectomy it was shown that SILS resulted in more procedure failures, more blood loss and took longer to perform.

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 subjects from surgical residents to surgeons who had performed laparoscopic surgery for approximately 20 years. However, these inter-individual 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 mm. pollicis brevis had to be excluded. Based on the results of the mm. extensor carpi radialis and the mm. flexor carpi ulnaris longus, we expect no differences in muscle activity in the thenar.

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 to maintain patient safety.
References


The physical workload of surgeons: a comparison of SILS and conventional laparoscopy
Ergonomics of laparoscopic graspers and the importance of haptic feedback: the surgeons’ perspective

Chantal C.J. Alleblas
Michel P.H. Vleugels
Theodoor E. Nieboer

Abstract

**Background:** Haptic feedback is drastically reduced in laparoscopic surgery compared to open surgery. Introducing enhanced haptic feedback in laparoscopic instruments might well improve surgical safety and efficiency. In the design process of a laparoscopic grasper with enhanced haptic feedback, handle design should be addressed to strive for optimal usability and comfort. Additionally, the surgeons’ perspective on the potential benefits of haptic feedback should be assessed to ascertain the clinical interest of enhanced haptic feedback.

**Methods:** A questionnaire was designed to determine surgeons’ use and preferences for laparoscopic instruments and expectations about enhanced haptic feedback. Surgeons were also asked whether they experience physical complaints related to laparoscopic instruments. The questionnaire was distributed to a group of laparoscopic surgeons based in Europe.

**Results:** From the 279 contacted subjects, 98 completed the questionnaire (response rate: 35%). Of all respondents, 77% reported physical complaints directly attributable to the use of laparoscopic instruments. No evident similarity in the main preference for graspers was found, either with or without haptic feedback. According to respondents, the added value of haptic feedback could be of particular use in feeling differences in tissue consistencies, feeling the applied pressure, locating a tumor or enlarged lymph node, feeling arterial pulse, and limiting strain in the surgeon’s hand.

**Conclusion:** This study stresses that the high prevalence of physical complaints directly related to laparoscopic instruments among laparoscopic surgeons is still relevant. Furthermore, the potential benefits of enhanced haptic feedback in laparoscopic surgery are recognized by laparoscopic specialists. Therefore, haptic feedback is considered an unmet need in laparoscopy.
Background

In laparoscopic surgery, haptic feedback should enable surgeons to perceive interaction forces between instrument and tissue. This is beneficial information regarding accurate regulation of tissue manipulation forces and recognition of tissue characteristics. In open surgery, the surgeon is able to manipulate tissue directly with the gloved hand, i.e. the surgeon directly perceives haptic feedback. In contrast, during laparoscopy the surgeon can only manipulate tissue indirectly due to the interference of instruments, which are inserted through small incisions. Consequently, haptic feedback is drastically reduced in laparoscopic surgery compared to open abdominal surgery. This is mainly caused by the friction within instruments and dynamic properties of the laparoscopic surgical setup.1,2 Introducing enhanced haptic feedback in laparoscopic instruments might well be beneficial for surgical safety and efficiency.

The results of several (pre)clinical studies show that haptic feedback is deficient in laparoscopic surgery.3-5 Moreover, intra-operative complications appear to be often the result of intentional actions, resulting in unintentional outcomes, caused by visual misperception.6-8 Additionally, surgical specialists have identified technology as one of the most important risk domain for patient safety.9 Tholey et al. found that the availability of both visual and haptic feedback leads to better tissue characterization than exclusively visual or haptic feedback.10 Previous studies argue for the implementation of enhanced haptic feedback to increase efficiency in terms of more successful grasping actions11 and accurate control over the instrument-tissue interaction forces.12 Two recently published literature reviews provide an overview of studies that have been performed regarding haptic feedback in minimally invasive surgery.2,13 The authors conclude that both patients and surgeons may well benefit from enhanced haptic feedback in minimally invasive surgical equipment. Although several technological efforts have been made in artificial settings it is argued that a clinically-driven approach should be deployed for a feasible application in surgical practice.14

Laparoscopic instruments are known to cause physical discomfort15,16 and moreover, to cause injuries especially affecting the thumbs.17,18 Furthermore, almost all laparoscopic handles come with the adage “one size fits all” whereas small hand size is a known risk factor for experiencing physical discomfort and difficulties in use of laparoscopic instruments.19-21 Instrument handles are the most important physical interface for laparoscopic surgeons.22 To strive for optimal usability and comfort, handle design should be specifically addressed during the design process of new types of surgical instruments.
Related to the development of a laparoscopic haptic feedback grasper, the tools that are already used in laparoscopy need to be evaluated. The involvement of end users in the design process is indispensible for suitability, safety and acceptance. Therefore, the aim of this study was to perform an evaluation of expert opinions regarding handle designs of currently used laparoscopic graspers and to determine surgeons’ needs and expectations regarding haptic feedback instruments.

Methods

A questionnaire was designed to determine the surgeons’ current use of instruments, their physical complaints related to instrument use as well as their needs and preferences for laparoscopic instruments. Furthermore, we aimed to identify expectations regarding haptic feedback in future instrument developments. The survey was distributed among attendees of the 23rd annual congress of the European Society for Gynecological Endoscopy (September, 2014) and the annual meeting of the Dutch Working Group for Gynecological Endoscopy (October, 2014). Additionally, an online version was distributed among the members of the Dutch Society of Endoscopic Surgery (January, 2015). The questionnaire was accompanied with an explanation of the aim and was subdivided into categories concerning demographics, physical complaints related to laparoscopic instrument use, handgrip assessment of currently used laparoscopic graspers, preferences for handle designs, and expectations regarding implementation of haptic feedback in laparoscopic surgery. Questions and answer options are presented in the Appendix. A descriptive data analysis was performed with SPSS software, version 22.

Findings

Demographics

In total, 279 subjects were contacted. The number of returned questionnaires was 98 (response rate 35%), among who were: 63 gynecologists, 27 general surgeons, 4 urologists, 2 pediatric surgeons and 2 medical technicians. The majority of respondents were male (68%). Four respondents were left-handed and 9 respondents were ambidextrous. All respondents worked in Europe of which the majority was established in The Netherlands (86%). Table 1 presents additional demographic data.
Ergonomics of laparoscopic graspers and the importance of haptic feedback: the surgeons’ perspective

Table 1  Demographic information.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Age in years</td>
<td>45.5</td>
</tr>
<tr>
<td>Glove size (general)</td>
<td>7.4</td>
</tr>
<tr>
<td>Glove size men</td>
<td>7.6</td>
</tr>
<tr>
<td>Glove size women</td>
<td>6.8</td>
</tr>
<tr>
<td>Years of experience</td>
<td>17.7</td>
</tr>
<tr>
<td>Years of experience in endoscopy</td>
<td>13.5</td>
</tr>
<tr>
<td>Endoscopic procedures per month</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Physical complaints

Overall, 77% of surgeons reported physical complaints directly attributable to the use of laparoscopic instruments. Figure 1 illustrates the prevalence of physical complaints as indicated for specific parts of the upper extremities. The frequency of discomfort in the palm of the hand from pressure caused by instruments as indicated by the surgeons is illustrated in Figure 2.26

Figure 1  Prevalence of physical complaints in the upper extremities (directly attributable to the use of laparoscopic instruments).
Handgrip assessment

Handles including indicated use and preferences by respondents are shown in Figure 3. The long-lever pistol grip was most commonly used. When combined, 99% of respondents indicated that they used at least one of the two types of scissors handles. Respondents were asked in what percentage of laparoscopic procedures they used each handle type. A total of 24% respondents indicated that they used the back-hinged scissors handle during all procedures. For the front-hinged scissors handle this was 32%. Less often used as standard equipment was the in-line handle (4%) and the long-lever pistol grip (12%) whereas the short-lever pistol grip was never reported to be used in all procedures. When specifically

Figure 2  Hand map including the frequency of reported areas of discomfort due to pressure caused by the instruments.

Figure 3  Presented handles for assessment including use and preference for current use and future haptic feedback instruments.

*HF = haptic feedback.
asked what kind of handle would be preferred for a haptic feedback instrument, the front-hinged scissors handle and the long-lever pistol grip were most frequently chosen. Regarding usability of handgrips, three aspects including functionality, comfort, and freedom of movement were assessed on a 7-point Likert scale. The long-lever pistol grip scored the highest on all three aspects (table 2).

<table>
<thead>
<tr>
<th>Handle</th>
<th>Functionality</th>
<th>Comfort</th>
<th>Freedom of movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scissors handle A</td>
<td>4.4 ± 1.8</td>
<td>3.8 ± 1.7</td>
<td>4.1 ± 1.5</td>
</tr>
<tr>
<td>Scissors handle B</td>
<td>5.0 ± 1.4</td>
<td>4.6 ± 1.4</td>
<td>4.9 ± 1.3</td>
</tr>
<tr>
<td>In-line handle</td>
<td>4.0 ± 1.6</td>
<td>4.6 ± 1.5</td>
<td>4.7 ± 1.6</td>
</tr>
<tr>
<td>Pistol grip A</td>
<td>5.3 ± 1.4</td>
<td>5.3 ± 1.4</td>
<td>5.0 ± 1.3</td>
</tr>
<tr>
<td>Pistol grip B</td>
<td>4.5 ± 1.8</td>
<td>4.6 ± 1.7</td>
<td>4.4 ± 1.6</td>
</tr>
</tbody>
</table>

*For illustrations of the handle types see Figure 3. Assessment was based on a 7-point Likert scale where 1 means ‘the worst’ and 7 means ‘the best’ for the constructs functionality and freedom of movement. Comfort was assessed on a 7-point Likert scale where 1 means ‘very uncomfortable’ and 7 means ‘very comfortable’.

Two extra user features were evaluated. Respondents were asked to estimate what percentage of time they positioned their index finger forward on the rotation knob of the handle. The majority (48%) of respondents reported to adopt this grip during less than a quarter of the overall procedure time and 16% reported to adopt this grip for over 75% of the procedure time. Furthermore, 51% of respondents indicated to control a scissors handle by means of a so-called ‘palm grip’ as illustrated in Figure 4. The most frequently reported reasons to do this were: in case of more static surgical steps, in case the application of more force is necessary, or in order to relieve strain or pressure on the thumb.

**Haptic feedback**

To estimate the added value of haptic feedback in clinical scenarios, respondents were asked to assess nine scenarios on a 6-point Likert scale where 0 means ‘not useful’ and 5 means ‘very useful’ for clinical practice. The results are presented in table 3. The possibility to feel differences in tissue consistencies and the ability to feel how much pressure is being applied were expected to be the most promising outcomes of integrated haptic feedback. Reduction of operation time and reduction of conversions to open surgery were least expected be a consequence of enhanced haptic feedback.
In this study, expert experiences and opinions regarding handle designs of laparoscopic graspers and regarding implementation of enhanced haptic feedback were evaluated. This study shows, with a prevalence of 77%, that physical complaints related to the use of laparoscopic instruments are commonly experienced. Whereas direct questioning revealed no similarity handgrip preference amongst the surgical specialists, the handgrip usability assessment results favored the long-lever pistol grip design. Furthermore, the results regarding the utility assessment of haptic feedback show clinical support for the implementation of enhanced haptic feedback in laparoscopic graspers.

* Assessment based on a 6-point Likert scale ranging from 0 – 5 and presented as mean ± SD.

**Table 3** Assessment of the utility of haptic feedback in clinical scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mean ± SD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeling differences in tissue consistencies</td>
<td>3.5 ± 1.5</td>
</tr>
<tr>
<td>Locating a tumor or enlarged lymph node</td>
<td>3.2 ± 1.7</td>
</tr>
<tr>
<td>Feeling arterial pulse</td>
<td>2.7 ± 1.6</td>
</tr>
<tr>
<td>Feeling how much pressure is being applied</td>
<td>3.6 ± 1.4</td>
</tr>
<tr>
<td>Limiting the force on the surgeon’s hand</td>
<td>3.4 ± 1.5</td>
</tr>
<tr>
<td>Lowering the time to complete surgery</td>
<td>2.4 ± 1.7</td>
</tr>
<tr>
<td>Reducing complications</td>
<td>3.2 ± 1.6</td>
</tr>
<tr>
<td>Reduction of conversions to open surgery</td>
<td>2.1 ± 1.6</td>
</tr>
<tr>
<td>Performing laparoscopy instead of open surgery</td>
<td>2.4 ± 1.7</td>
</tr>
</tbody>
</table>

**Discussion**

In this study, expert experiences and opinions regarding handle designs of laparoscopic graspers and regarding implementation of enhanced haptic feedback were evaluated. This study shows, with a prevalence of 77%, that physical complaints related to the use of laparoscopic instruments are commonly experienced. Whereas direct questioning revealed no similarity handgrip preference amongst the surgical specialists, the handgrip usability assessment results favored the long-lever pistol grip design. Furthermore, the results regarding the utility assessment of haptic feedback show clinical support for the implementation of enhanced haptic feedback in laparoscopic graspers.
Exposure to risk factors for developing physical complaints should obviously be avoided. In the context of laparoscopic instrument use these risk factors involve: adverse postures and motions of the upper extremities, adverse force exertion and excessive local pressure or friction in the contact surface between instrument and hand. Other risk factors, including precise working and repetitive movements, are apparently inherent to tasks that are to be performed during laparoscopic surgery. However, these factors can also be reinforced by suboptimal surgical instrument design.

Respondents did not show evident similarity in their main preference for graspers, either with or without haptic feedback. However, the long-lever pistol grip was best appraised in the usability assessment. 51% of respondents do sometimes control a scissors handle by means of a so-called palm grip, which approaches the hand posture when controlling a pistol grip. Moreover, our results emphasize that discomfort as a result of contact pressure is frequently experienced in the thumb and thenar area. Based on the indicated use of instruments we concluded that this pressure induced discomfort are a result from the use of scissors-handles. Additionally, two recent studies also reported clinical support for a pistol grip handle design. A pistol grip would specifically meet the need to alleviate contact stress during instrument control. In summary these results suggest that a haptic feedback grasper is best equipped with a pistol grip.

As mentioned in the background section, laparoscopic handles usually come with the adage "one size fits all". A laparoscopic stapler generally comes with a long-lever pistol grip. Sutton et al. reported that the handles of these devices are too big for a certain group of surgeons, particularly women, who have significantly smaller hands than men. Therefore, two or more sizes should be considered to ascertain suitability for the whole range of end users.

The potential benefits which haptic feedback yields are acknowledged by the respondents. More specifically, according to laparoscopic specialists, enhanced haptic feedback could be of particular use in feeling differences in tissue consistencies, feeling how much pressure is being applied, locating a tumor or enlarged lymph node, feeling arterial pulse and enhanced instrument ergonomics in terms of limiting the force on the surgeon’s hand.

This study provides directives for the handle design of a haptic feedback grasper. As suggested by Matern et al. during the design process of surgical instruments, muscle activity and task performance under dynamic conditions should be considered. Based on the results of the questionnaire and the principles of haptic feedback we may hypothesize that haptic feedback is an unmet need in laparoscopic surgery. Along with the development of such a device, the assessed user scenarios should be examined in (pre-)clinical experimental research.
Rather than a direct assessment of readily available instruments, this assessment was based on pictures which can be considered as a limitation of our study. A large group of respondents report to use a front-hinged scissors handle, whereas the vast majority of scissors handles used are equipped with back-hinged actuation. We might consider this an artifact of the used method, but we might as well question whether surgeons are aware of the actuation of the instrument. Lastly, since the vast majority of respondents were Dutch, we have to be reticent to extrapolate these findings to Europe as a whole.

**Conclusion**

This study highlights the clinical importance of well designed ergonomic laparoscopic instruments. Moreover, the need of haptic feedback in laparoscopic surgery is recognized by surgeons of different disciplines. Both patients and surgeons may well benefit from the implementation of enhanced haptic feedback in laparoscopic instruments.
References

### Appendix  Survey questions.

#### Demographics

<table>
<thead>
<tr>
<th>Question</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is your age?</td>
<td>N</td>
</tr>
<tr>
<td>What is your gender?</td>
<td>S</td>
</tr>
<tr>
<td>In which country do you work?</td>
<td>S</td>
</tr>
<tr>
<td>In what department do you work?</td>
<td>S</td>
</tr>
<tr>
<td>What is your dominant hand?</td>
<td>S</td>
</tr>
<tr>
<td>What is your surgical glove size?</td>
<td>N</td>
</tr>
<tr>
<td>For how many years are you in practice?</td>
<td>N</td>
</tr>
<tr>
<td>For how many years do you perform laparoscopic surgery?</td>
<td>N</td>
</tr>
<tr>
<td>How many laparoscopic procedures do you perform per month?</td>
<td>N</td>
</tr>
</tbody>
</table>

#### Physical symptoms

<table>
<thead>
<tr>
<th>Question</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you ever experienced physical complaints or discomfort that you would attribute to the use of laparoscopic instruments?</td>
<td>S</td>
</tr>
<tr>
<td>If applicable, in which parts of the upper extremities* have you experienced these physical complaints or discomforts?</td>
<td>M</td>
</tr>
<tr>
<td>If applicable, where do you experience discomfort from pressure caused by instruments? (includes the hand map assessment# as illustrated in Figure 2)</td>
<td>M</td>
</tr>
</tbody>
</table>

#### Handgrip assessment

<table>
<thead>
<tr>
<th>Question</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>In what percentage of laparoscopic procedures do you use these handle types?</td>
<td>N</td>
</tr>
<tr>
<td>Which handle type is your favorite for grasping?</td>
<td>S</td>
</tr>
<tr>
<td>How do you rate the functionality of each handle type for grasping tasks?</td>
<td>L</td>
</tr>
<tr>
<td>How do you rate the comfort of each handle type for grasping tasks?</td>
<td>L</td>
</tr>
<tr>
<td>How do you rate the freedom of movement of each handle type for grasping tasks?</td>
<td>L</td>
</tr>
<tr>
<td>Which handle type would be your favorite for grasping with an instrument that provides enhanced haptic feedback?</td>
<td>S</td>
</tr>
</tbody>
</table>

#### User features

<table>
<thead>
<tr>
<th>Question</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>When holding a laparoscopic grasper with rotating function for the instrument tip, what percentage of time do you keep your index finger pointed forward?</td>
<td>N</td>
</tr>
<tr>
<td>Do you sometimes ‘palm’ your grip when operating with a scissors handle?</td>
<td>S</td>
</tr>
<tr>
<td>If so, in what situations do you do this?</td>
<td>D</td>
</tr>
</tbody>
</table>

#### Clinical relevance

<table>
<thead>
<tr>
<th>Question</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>If you had a laparoscopic tool with haptic feedback, for what specific scenarios would you consider it useful?</td>
<td>L</td>
</tr>
<tr>
<td>- Feeling differences in tissue consistencies.</td>
<td></td>
</tr>
<tr>
<td>- Locating a tumor or enlarged lymph node.</td>
<td></td>
</tr>
<tr>
<td>- Feeling arterial pulse.</td>
<td></td>
</tr>
<tr>
<td>- Feeling how much pressure is being applied.</td>
<td></td>
</tr>
<tr>
<td>- Limiting the force on the surgeons hand.</td>
<td></td>
</tr>
<tr>
<td>- Lowering the time to complete surgery.</td>
<td></td>
</tr>
<tr>
<td>- Reducing complications.</td>
<td></td>
</tr>
<tr>
<td>- Reduction of conversions to open surgery.</td>
<td></td>
</tr>
<tr>
<td>- Performing laparoscopy instead of open surgery.</td>
<td></td>
</tr>
</tbody>
</table>

D = descriptive; L = Likert scale; M = Multiple answers; N = numeric response; S = single answer.

* body parts involved: wrists, fingers, thumbs, elbows, shoulders.

* Handgrip assessments concerned evaluation of the following designs: back-hinged scissors handle; front-hinged scissors handle, in-line handle, long-lever pistol grip, short-lever pistol grip.
The effects of laparoscopic graspers with enhanced haptic feedback on applied forces: a randomized comparison with conventional graspers

Chantal C.J. Alleblas
Michel P.H. Vleugels
Sjors F.P.J. Coppus
Theodoor E. Nieboer

Surgical Endoscopy 2017;31(12):5411-5417
Abstract

Background: Haptic feedback, which enables surgeons to perceive information on interaction forces between instrument and tissue, is deficient in laparoscopic surgery. This information, however, is essential for accurate tissue manipulation and recognition of tissue consistencies. To this end, a laparoscopic grasper with enhanced haptic feedback has been developed: the Force Reflecting Operation Instrument (FROI). This study tested the effects of enhanced haptic feedback on force control, tissue consistency interpretation, and the associated surgeons’ level of confidence through a randomized controlled crossover experiment.

Methods: A randomized three-period crossover trial was conducted, in which seven surgical residents and thirteen medical students participated. The setup involved a box trainer in which slices of porcine organs (lung, small intestine, or liver) were presented. Participants performed three series of blinded palpation tasks involving three different graspers: the conventional grasper, the FROI with enhanced haptic feedback activated, and the FROI with enhanced haptic feedback deactivated. In each series, nine pairs of organ tissues were palpated to compare consistencies. The orders of presenting both instruments and tissues were randomized.

Results: The force applied during tissue palpation significantly decreased, by a mean factor of 3.1 with enhanced haptic feedback. Tissue consistency interpretation was significantly improved with more correct assessments and participants answered with significantly more confidence when enhanced haptic feedback was available.

Conclusion: The availability of enhanced haptic feedback enabled participants to operate with significantly reduced interaction force between instrument and tissues. This observation is expected to have multiple important clinical implications, such as less tissue damage, fewer complications, shorter operation times, and improved ergonomics.
Introduction

Since the early 1990s, when the implementation of laparoscopic surgery began to increase, its complexity has been highlighted. In addition to the reduced degrees of freedom in instrument movement, interference from cameras and other instruments has eliminated direct visual feedback and haptic feedback. However, technological advances and sophisticated equipment have found their way into clinical practice, evident from improvements in visual feedback and the introduction of robotic surgery. Nevertheless, haptic feedback is still deficient in conventional laparoscopy, and it is completely lost in robotic surgery. The implementation of haptic feedback in laparoscopic instruments has not yet found its way into clinical practice. This is remarkable because explicit attention was drawn to this topic over a decade ago and the hand-assisted laparoscopic surgical technique was introduced in the late 1990s especially for the benefits of direct tissue palpation. Furthermore, several technological efforts have focused on the problem.

Introducing enhanced haptic feedback might well be the next big advancement in laparoscopic surgery, and both patients and surgeons stand to benefit. From a broad perspective, haptics involves the sense of touch and human interactions with the environment through touch. Haptic perception incorporates tactile and kinaesthetic perception. Tactile perception is based on receptors in our skin, which detect pressure, vibration, and texture. Kinaesthetic perception is based on receptors in our muscles, tendons, and joints. They detect position, movement, and force. When translating this to surgery, haptic perception is essential for accurate tissue identification and for accurate control over applied forces during tissue manipulations. These two abilities have been specifically acknowledged as important by laparoscopic specialists. Up to now, in laparoscopic surgery, the surgeon has to rely on visual feedback and experience to estimate the appropriate amount of grasping force. Moreover, it has been reported that visual cues can be interpreted, with experience, as haptic information. However, it was also found that providing both visual and haptic feedback could lead to better performance than either visual or haptic feedback alone.

Previous experimental studies have revealed that haptic feedback was significantly reduced in laparoscopic surgery compared to open surgery. Ottermo et al. found that the use of laparoscopic graspers decreased the accuracy of tissue recognition by fivefold. Den Boer et al. reported that the perception of pulsation was reduced by at least a factor of 8. Heijnsdijk et al. found that the applied grip force in laparoscopy was at least twofold higher than necessary to manipulate tissue. Those results suggested that, although it may be possible to receive some haptic feedback from laparoscopic graspers, the amount of haptic feedback about tissue properties and tissue reactions lacks clinical relevance for delicate tissue manipulation. With this study, we aimed to investigate the effects of...
enhanced haptic feedback on force control, tissue consistency interpretation, and associated surgeons’ level of confidence.

Materials and methods

A special technique, involving “optical fiber Bragg grating” technology, has been deployed to introduce haptic feedback in a laparoscopic grasper that can be used in a clinical setting.23 A prototype laparoscopic grasper with enhanced haptic feedback has been developed, called the Force Reflecting Operation Instrument (FROI). This instrument is capable of measuring the force applied on tissue with the instrument tip and transmits this information to the surgeon through a resistance mechanism in the instrument handle.

Participants

Residents with laparoscopic experience were recruited through a request directly distributed by e-mail to all gynaecological residents affiliated with the Radboud University Medical Center, Nijmegen, The Netherlands. Additionally, medical students were recruited through a similar request placed on the medical faculty’s online bulletin board. Both requests stated the aim of the study and provided a summary of the experimental study design.

Experimental design and procedure

Experiments took place in the Central Animal Laboratory (CDL), Nijmegen, The Netherlands. This study was designed in consultation with an animal welfare officer and a zoological technical analyst affiliated with the CDL. No approval from the Dutch Central Committee on Animal Studies (CCD) was required, because no live animals were used in this study. Fresh porcine organ tissue (slaughterhouse material) was provided by the CDL and processed according to the CDL regulations. The experimental setup involved a box trainer. Fresh slices of porcine organs (lung, small intestine, and liver) were presented in the box (Figure 1). Before the trial was conducted, the appropriateness of these tissues was assessed by two laparoscopic experts and two novices. All four were able to distinguish lung from small intestine and liver and vice versa while palpating the tissues with a gloved hand (as in open surgery) and without any visual feedback. Furthermore, the FROI technology allows the surgeon to predefine the actual level of feedback he or she prefers to work with (i.e. the predefinition of the gain of resistance in the instrument handle). For this study, the level of feedback was predefined through a face validity test with two laparoscopic experts. Participants performed three series of blinded palpation tasks, involving three different graspers: a conventional grasper and the FROI grasper (Figure 2), which was used in the activated and deactivated states. In the deactivated state, the FROI enabled force registration without the use of enhanced haptic feedback. Each series involved nine pairs of porcine organ tissues. Through blinded palpation, participants had
to compare the tissue consistencies of the two presented tissues and determine which tissue had the most solid consistency. The comparison could involve slices of two different organs (e.g., lung versus liver) or slices of the same organ. Participants were not restricted in the number of palpations of the tissues or the total palpation time. The orders of presenting both the instruments and the tissues were randomized between subjects following a randomized controlled crossover design. A computer-generated randomization was executed with block size 3 and list length 60 for the randomization of instrument order and block size 9 and list length 540 for the randomization of tissue comparison. A single-blind approach was applied for the palpation of tissues. Blinding for the instruments was not attainable due to the design of instruments and experimental setup.

Data collection
To record all reaction forces (concentrated load, in Newtons [N]) on the instrument tip of the FROI device (activated and deactivated), the optical signals in the instrument were measured with a Deminsys interrogator. A Spartan-6 field-programmable gate array and an Arduino Mega 2560 controller were interposed to enable reading the forces with a Python script and storing the data on a Windows PC. The forces were recorded at a sampling rate of 10 samples/s. Participants determined which tissue they thought had the

Figure 1 Experimental setup shows the box trainer. The participant stands on the left for holding the grasper, and the instructor on the right for placing the tissues in front of the grasper tip.
most solid consistency, and after each palpation, they recorded their assessment on an answer form. The answer form included the options ‘left’, ‘right’, or ‘no difference’. Additionally, participants had to rate their level of certainty on a 5-point Likert scale, ranging from very unconfident to very confident.

Data analysis
All files were analysed by means of a protocol written in MATLAB R2014b (The Mathworks, Inc., Natick, MA, USA). All peak forces were selected, and the average peak force was calculated per grasper for each subject in a series of palpation tasks.

Statistics
Statistical analyses were carried out with IBM SPSS 22 (SPSS, Inc., Chicago Ill, USA). To determine whether the use of the FROI mechanism had an effect on the applied force during tissue manipulation, we performed a paired samples t-test. To determine whether the use of the FROI had an impact on tissue recognition and confidence in the answer, a Generalized Estimating Equations (GEE) analysis was performed. For tissue recognition, the outcome was modelled as a function that included the type of grasper, the type of tissue, and the interaction between the grasper and the type of tissue. For confidence, the outcome was modelled as a function that included the type of grasper and answer correctness (data are presented as odds ratios (OR) with 95% Confidence Interval (CI)). For both analyses, a $P$ value $<.05$ was considered statistically significant.
Results

In total, 7 residents (6 females) and 13 medical students (8 females) participated in this study. Residents had an average of 3.5 years of laparoscopic experience.

Force application

Due to a technical error in the data-acquisition software, data on force application was incompletely stored in eight cases. To prevent improper data interpretation, we only analysed the force application data collected from twelve participants. There was compliance with the assumption of normality which allowed the use of the Paired Samples T-Test. On average, the applied force was lowered by a factor of 3.1 (SD 0.4) with the enhanced haptic feedback feature, compared to the conventional situation. The direction of this effect was consistent for all participants, regardless of their experience and the type of palpated tissue. Overall, during palpation, participants applied average forces of 4.6 N (SD 1.5) without haptic feedback, and 1.7 N (SD 0.7) with the addition of haptic feedback. This difference in applied force (2.9 N, 95% CI: 2.0 - 3.8) was significant (p <.001). In Figure 3, two graphs depict the typical force application during a palpation task.

![Figure 3](image_url)

**Figure 3** Force application during tissue palpation. These recordings of one participant show forces applied with the FROI with enhanced haptic feedback activated (*left*) and forces applied with enhanced haptic feedback deactivated (*right*).

Tissue discrimination

Table 1 shows the percentages of correct assessments in the tissue consistency comparisons for each grasper and for each type of comparison. In cases where the participant palpated two slices of the same tissue, no significant differences were found in the outcomes between the different types of graspers. However, when the participant palpated slices of different tissues, both the activated FROI (p = 0.027) and the deactivated FROI (p = 0.008) provided significantly enhanced performance compared to the conventional grasper. There was no significant difference for the activated FROI compared to the deactivated FROI (p = 0.297).
Confidence in Assessments

Figure 4 shows the 5-point Likert scale data for confidence per grasper. The use of the activated FROI was associated with a higher odds ratio for more confidence when compared to both the conventional grasper (OR 1.9, 95% CI 1.4 – 2.4, p <0.001) and the deactivated FROI (OR 1.4, 95% CI 1.1 – 1.8 p = 0.022). Overall, we found that correct assessments were associated with a higher odds ratio for level of confidence compared to incorrect assessments (OR 2.2, 95% CI 1.7 – 2.8, p<0.001).

Table 1 Percentage of correctly assessed tissue consistencies for each grasper and each type of comparison.

<table>
<thead>
<tr>
<th>Tissues compared</th>
<th>Conventional</th>
<th>FROI activated</th>
<th>FROI deactivated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different tissues</td>
<td>52 (42 - 61)</td>
<td>63 (53 – 71)</td>
<td>69 (60 - 78)</td>
</tr>
<tr>
<td>Equivalent tissues</td>
<td>47 (35 - 58)</td>
<td>40 (28 – 53)</td>
<td>48 (34 - 63)</td>
</tr>
</tbody>
</table>

Data represent the estimated mean percentage (95% confidence interval). Percentages are based on all 540 cases (20 participants; 9 assessments; 3 instruments).

Figure 4 Distribution of the level of self-reported confidence on a 5-point Likert scale for each type of grasper.
**Discussion**

In this study, we examined whether enhanced haptic feedback in laparoscopic graspers could affect hand-tool-tissue interactions. We found that the addition of haptic feedback resulted in an average of 3.1-fold less applied force on the tissue. Furthermore, the use of the FROI resulted in better tissue discrimination ability and higher confidence in decision-making.

Our finding that haptic feedback in the laparoscopic grasper resulted in significantly less force on the tissue was consistent with findings in previous studies.²²,²⁴,²⁵ Because the palpation of tissue in our study was performed in a blinded manner, the effect was not influenced by visual feedback. Lowering the applied force on tissues may have several clinical implications. First, less force is likely to lead to less tissue trauma. A recent study on integrated tactile feedback in robotic surgery on the porcine bowel has shown that this feedback led to a significant decrease in the grasping force and in the overall incidence of tissue damage.²⁶ A study by Heijnsdijk et al. showed that the mean laparoscopic force applied in bowel handling was 6.8 N, whereas the force required to prevent slippage was 3.0 N.²² During long laparoscopic procedures, such as hemicolecotomy or hysterectomy, a reduction in applied forces is likely to lead to less tissue trauma and, possibly, faster recovery for patients. From the surgeons’ perspective, reduced force application will likely result in a reduction in physical fatigue and, in the long term, a reduction in musculoskeletal disorders due to strenuous surgery. The presence of fatigue or musculoskeletal disorders during surgery has increasingly become recognized as a cause for impaired quality in laparoscopic surgical care.²⁷,²⁸ Ideally, both patients and surgeons will benefit from instruments with haptic feedback.

We observed that the use of the FROI, whether activated or deactivated resulted in better ability to discriminate between palpated tissues. In an earlier study, experienced laparoscopic surgeons stated that the expected advantages of haptic feedback were, among other things, an ability to feel differences in tissue consistencies and in the amount of force applied.¹⁷ The recognition of tissue characteristics will probably be of benefit in surgical procedures such as ovarian cyst removal, malignant disease staging, deep infiltrating endometriosis treatment, and bowel surgery. Furthermore, this feature may facilitate a laparoscopic option for indications that up to now required open abdominal procedures; e.g., surgery that requires lymph node palpation. Haptic feedback in laparoscopic surgery is expected to result in fewer conversions to open surgery. It should also be highlighted that, compared to the conventional grasper, the FROI performed better in tissue recognition, even when the haptic feedback option was switched off. This advantage probably resulted from the low internal friction inside the instrument. However, the FROI was only superior for tissue recognition when there was a difference between the presented tissues.
The third goal of this study was to investigate the effect of enhanced haptic feedback on confidence in decision-making, which is a valuable parameter regarding any human-product interaction. When the tissue discrepancy was correctly determined, we observed that haptic feedback significantly improved the level of self-reported confidence on a 5-point Likert scale. For patient safety, it is of specific interest to determine differences in the level of confidence associated with correct assessments versus the confidence associated with incorrect assessments. Clearly, it is important to avoid great confidence in an erroneous assessment. The present experiment enabled us to link the confidence level to task performance. For all graspers, we found that the level of confidence was significantly higher for correct determinations than for incorrect determinations.

There was little difference between FROI activated and deactivated regarding tissue consistency discrimination and confidence as shown in table 1 and figure 4 respectively. However, from our data it can be concluded that better differentiation already benefits from eliminating the internal losses within the instrument (friction and play). Although not very likely, additional studies will have to reveal if a type II error could have occurred. Furthermore, better or more careful tissue handling solely resulted from the haptic feedback modality activated, as shown in the typical example in figure 3.

Although the current generation of laparoscopic surgeons has not received any formal training in laparoscopic instruments with haptic feedback, it is expected that current residents are more acquainted with this type of instrument. Several studies have reported on the introduction and validation of (virtual) laparoscopic training systems with haptic and force feedback. In their review on haptic feedback simulations, Pinzon et al. concluded that force feedback was the best method for tissue identification, and that haptic feedback provided the greatest benefit to surgical novices in the early stages of their training. Prasad et al. compared laparoscopic novices and experts and found that novices applied large forces compared to expert surgeons. Furthermore, they found that visual and haptic feedback improved the performance of residents. Therefore, the implementation of haptic feedback in laparoscopic training programs will most likely benefit skills training, and consequently, laparoscopic performance and patient outcomes. The exception might be laparoscopic suturing, which appeared to be learned more readily in conventional box trainers than in virtual reality systems with haptic feedback.

This study had some limitations. First, the number of participants was rather small. Furthermore, due to software issues, not all force patterns could be evaluated. Also, we did not find different results between laparoscopic residents and students; both groups applied the same (high) forces with graspers that lacked haptic feedback. This result was probably due to the fact that both residents and students used the FROI for the first time in this experiment. Lastly, several porcine tissue pairs might not have differed from each other sufficiently to allow definite discrimination.

Several directives for future research can be derived based on the knowledge obtained in this study. Future studies could address the speed of decision-making, which
was not tested in this study. Also, future studies should separately address the advantages of haptic and visual feedback, to enable clear distinctions between the added values of these two effects. The technique implemented in the current study was performed with a conventional laparoscopic grasper with the well-known scissor-like hand grip; this grasper enabled a comparison between haptic feedback and no haptic feedback with standard equipment. For future studies, current knowledge on the ergonomics of several hand grips should be taken into account.

In conclusion, we found that the FROI as a haptic feedback laparoscopic grasper enabled surgeons to handle tissues with significantly reduced interaction forces between the instrument and tissue. The observed force reduction is expected to have multiple important clinical implications, including less tissue damage, fewer complications, shorter operation times, and enhanced ergonomics. Future in vivo studies are needed to validate the anticipated clinical benefits.
## References

The effects of laparoscopic graspers with enhanced haptic feedback on applied forces


Performance of a haptic feedback grasper in laparoscopic surgery: a randomized comparison with conventional graspers in a porcine model

Chantal C.J. Alleblas
Michel P.H. Vleugels
Martijn W.J. Stommel
Theodoor E. Nieboer

Submitted
Abstract

Background: Compared to open surgery, minimally invasive surgery is limited by drastically reduced sensation of tissue properties. A laparoscopic grasper with integrated haptic feedback technology that enables surgeons to sense tissue properties might provide a solution to this limitation. The Force Reflecting Operation Instrument (FROI) is a new laparoscopic grasper, designed to provide information about the interaction forces between the instrument and tissue through resistance in the instrument handle. We previously completed simulation studies to optimize the features of the FROI. The present study aimed to assess the functionality of the FROI compared to a conventional grasper in an in vivo setting.

Methods: In this randomized, two-period crossover trial, we used a standard laparoscopic surgical setup to perform laparoscopic surgery in pigs. Eleven laparoscopic experts performed paired colorectal, gynecological, or urological procedures, once with the FROI and once with a conventional grasper. Participants were asked to complete the NASA Task Load Index rating scale after each procedure and evaluate five specific features for both graspers on a six-point Likert scale. To capture opinions on the overall functionality of the FROI compared to a conventional grasper, participants responded to eight open questions.

Results: The surgeons reported that the use of the FROI significantly improved tissue consistency perception, arterial pulse detection, and force control, compared to the conventional grasper. No significant differences were found in surgeons’ muscular strain or operative time. The most emphasized points in the open questions were the improved soft tissue handling and the importance for complex procedures.

Conclusion: This study validated the superiority of the FROI in tissue consistency sensation, arterial pulse detection, and force control, compared to a conventional grasper, in an in vivo setting. Moreover, a multispecialty group of expert laparoscopic surgeons confirmed the added value of haptic feedback technology in a live surgical setting.
Introduction

In minimally invasive surgery, the lack of direct tissue palpation, due to the use of laparoscopic graspers, has significantly changed the haptic perception of surgeons. Thus, surgeons must plan their actions based on distorted haptic feedback perceived through instrument handles. Haptic feedback is hampered by mechanical backlash and friction in the instruments. Indeed, studies have shown that haptic feedback is drastically reduced in minimally invasive surgery and that the remaining haptic feedback might well lack any clinical relevance. Expert surgeons might base their actions on so-called ‘visual haptics’, where forces and tissue consistencies are estimated through visual feedback from instrument-tissue interactions. However, both visual and haptic feedback are required for the best performance.

Literature reviews have suggested that the implementation of enhanced haptic feedback might improve surgical safety and efficiency and provide multiple benefits to surgical performance. Based on the principles of haptics, one benefit is that tissue consistencies can be better estimated; this capability can be particularly useful in differentiating abnormal from normal tissues. Another benefit is that accurate haptic feedback about tissue properties may enable surgeons to improve control and reduce the interaction forces between the instrument tip and the tissue. This feature may prevent accidental tissue damage. Moreover, increasing the usability of laparoscopic instruments might reduce strain in the surgeon's hand and improve ergonomics in minimally invasive surgery. Furthermore, enhanced haptic feedback might provide the benefit of arterial pulse detection, which could facilitate a targeted arterial approach or prevent accidental dissection of arteries that are hidden within structures. With these combined benefits, the implementation of haptic feedback could eventually reduce the time required to complete surgery, reduce complications, and reduce the number of cases converted to open procedures. In addition to these theoretical assumptions, laparoscopic experts have confirmed the added value of haptic feedback.

These potential clinical benefits were pursued with the development of a new laparoscopic grasper with enhanced haptic feedback, the Force Reflecting Operation Instrument (FROI) (Figure 1). An iterative design approach, based on close cooperation between surgeons and engineers, and extensive laboratory testing have refined the FROI into a fully functional instrument with real-time haptic feedback. Haptic feedback was accomplished with the introduction of “optical fiber bragg grating” technology. This technology provides haptic feedback in a natural, and intuitive way, through a resistance mechanism in the trigger of the instrument handle, instead of additional visual feedback, audio cues or vibrations. The FROI was validated for its abilities to reduce force and enhance tissue recognition in a previous experimental study. As an added element, the FROI does provide an audio
warning when a surgeon exerts grip forces associated with tissue damage and has a mechanical break that activates when the grip force is passing a pre-specified limit. However, its utility in a clinical setting remains to be validated. Therefore, this study aimed to assess the functionality of the FROI compared to a conventional grasper in a porcine model and an in vivo setting.

![The force reflecting operation instrument.](image)

**Figure 1** The force reflecting operation instrument.

**Methods**

In compliance with the Dutch policy on animal studies, the design of this experiment was first controlled by the local animal welfare officer of the Central Animal Laboratory of Nijmegen. Thereafter, the study was approved by the Dutch Central Authority for Scientific Procedures on Animals.

**Participants**

Surgeons of several disciplines and different nationalities participated, including specialists in gastrointestinal surgery, urology, gynecology and veterinary surgery. Surgeons were invited by one of the authors and compensation for travel expenses was provided.

**Experimental design and procedure**

A standard laparoscopic surgical setup (provided by Olympus Nederland BV, Leiderdorp, Netherlands) was used to perform laparoscopic surgery on three female farm pigs (approximately 60 kg). Each pig was used on a different day. A minimum of six and at most ten surgical procedures were conducted on each pig. All procedures were performed under the supervision of a zoological analyst. A randomized, two-period, crossover trial
was conducted. All participants performed one type of laparoscopic procedure twice; a participant might perform two partial small bowel resections, two partial ureter dissections, bilateral hemi-hysterectomy or bilateral ovarectomy. In randomized order, each surgeon used the FROI once and the conventional grasper once to perform the lifting and grasping part of the procedure. Additionally, surgeons were provided with a cutting and dissecting device (Thunderbeat, Olympus Medical Systems Corp., Tokyo, Japan). All participating surgeons were assisted by a first assistant and a scrub nurse (Figure 2).

![Figure 2](image-url) Overview of the surgical setup.

The surgeon is standing on the right side, with the FROI in his left hand and the cutting and dissecting device (Thunderbeat, Olympus Medical Systems Corp., Tokyo, Japan) in his right hand. The assistant is in the middle holding the endoscope. The scrub nurse is on the left, holding the cord of the cutting and dissecting device.

### Data collection

All data were collected through four questionnaires. The first questionnaire collected demographic data, including nationality, specialty, age, surgical glove size, dominant hand, years of experience in laparoscopy, and the number of laparoscopic cases performed per month. To control for variations in the demand and complexity of procedures, surgeons were instructed to complete the NASA Task Load Index (NASA-TLX) immediately after each procedure. The NASA-TLX is a multidimensional scale designed to estimate the workload of one or more operators, assessed during or immediately after performing a.
task. The index includes the domains of Mental Demand, Physical Demand, Temporal Demand, Overall Performance, Frustration Level, and Effort. The NASA-TLX has been validated, and it is widely used for evaluating surgical procedures.21,22 In addition, we added the subscale “task complexity” based on the surgery task load index (SURG-TLX), which is a derivative of the NASA-TLX.23 The third questionnaire was completed immediately after the surgeon finished both procedures. Participants were asked to assess five specific features (Figure 3) of the laparoscopic graspers on a semantic, six-point Likert scale, which ranged from zero to five. Additionally, participants were asked to anticipate four potential effects of the FROI application, compared to effects of the conventional grasper, in human clinical scenarios. The effects were also rated on a six-point Likert scale (Figure 4). The fourth questionnaire was designed to capture opinions regarding the overall experience with the FROI compared to a conventional grasper. Participants were asked to complete eight open questions (table 1).

Statistics
Statistical analyses were performed with IBM SPSS Statistics 22 (SPSS, Inc., Chicago Ill, USA). Wilcoxon signed rank tests were used to compare non-parametric paired data for both NASA-TLX scores and instrument feature assessments. A p-value <.05 was considered statistically significant.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Survey of open questions regarding opinions of overall experiences with the FROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Please give a short description of your overall impression of the FROI</td>
</tr>
<tr>
<td>2.</td>
<td>Do you consider the FROI effective in use (grasping, slips, re-grips etc.)? (Please describe)</td>
</tr>
<tr>
<td>3.</td>
<td>Does the FROI assist in tissue recognition, diagnosis, and differentiation? Would you consider this feature clinically relevant?</td>
</tr>
<tr>
<td>4.</td>
<td>Do you believe the FROI could be useful for minimizing tissue damage in human surgery?</td>
</tr>
<tr>
<td>5.</td>
<td>Was the FROI comfortable to use? Please substantiate your answer.</td>
</tr>
<tr>
<td>6.</td>
<td>Would you be willing to use the FROI in human laparoscopic surgery?</td>
</tr>
<tr>
<td>7.</td>
<td>What is your expectation regarding the impact of the FROI on the learning curve for residents?</td>
</tr>
<tr>
<td>8.</td>
<td>What is your assessment of the safety of the FROI? Would you expect any safety concerns?</td>
</tr>
</tbody>
</table>
Results

Eleven male laparoscopic specialists participated in this trial, including four gastrointestinal surgeons, four gynecologists, two urologists, and one veterinary surgeon. The nationalities of these surgeons were The Netherlands, Belgium, Germany, and the United Kingdom. Eight surgeons were right-handed, two were left-handed, and one was ambidextrous. The surgical glove sizes were 8.0 for eight surgeons and 7.5 for three surgeons. The average age was 51 years (SD = 12) and the average years of experience in laparoscopic surgery was 19 years (SD = 11). The average laparoscopic caseload per month was 22 cases (SD = 16).

Twenty-four procedures were conducted (twelve with each grasper), including ten partial bowel resections, six hemi-hysterectomies, two ovariectomies, and six partial ureter dissections. All procedures were successfully completed. No significant differences between procedures were found on the NASA-tlx scores. Thus, the results were not influenced by differences in workload or complexity.

A six-point Likert scale was used to assess five different grasper features (Figure 3). The use of the FROI significantly improved the ability to feel the difference in tissue consistency compared to the conventional grasper (median 4 (range 3-5) vs. median 2 (range 1-4); \( Z = -2.895, p = 0.004 \)). The use of the FROI was significantly superior in the ability to feel arterial pulse compared to the conventional grasper (5 (2-5) vs. 0 (0-2); \( Z = -2.971, p = 0.003 \)). Consistent with the ability to feel differences in tissue consistency, the use of the FROI significantly improved the ability to feel how much pressure was applied compared to the conventional grasper (4 (3-5) vs. 2 (0-3); \( Z = 2.820, p = 0.005 \)). No significant difference was observed in the time to complete surgery between the FROI and the conventional grasper (3 (0-4) vs. 3 (0-4); \( Z = 0.184, p = 0.854 \)). Due to the high variance in the ratings of both instruments, no significant difference was observed in the muscular strain in the hand, between the FROI and the conventional grasper (4 (0-5) vs. 2 (0-4); \( Z = 0.976, p = 0.329 \)).

Surgeons were asked to assess four potential effects of the FROI application in clinical scenarios, compared to the current surgical setup on a six-point Likert scale. Figure 4 shows the overall distribution of responses.
**Figure 3** Distribution of surgeon responses to questions about the features of both graspers.

*(Left)* Images depict the different surgical instruments, and *(right)* graph shows the features and corresponding responses for each grasper. Ratings (color-coded) are quantified as percentages of the total cohort (N=11 surgeons), and they are shown cumulatively on the X-axis.

**Figure 4** Distribution of responses to questions about the effects of the FROI in clinical scenarios.

Graph shows the effects of the FROI and corresponding responses. Ratings (color-coded) are quantified as percentages of the total cohort (N=11 surgeons), and they are shown cumulatively on the X-axis.
The final questionnaire (table 1) asked surgeons to describe their overall impressions. Six participants mentioned that the FROI improved soft tissue handling, because it provided more accurate feedback on tissue resistance. Additionally, four surgeons appraised the technology as a promising addendum for surgery. According to five surgeons, the effectiveness of the FROI was limited by the grasper tip design. Although the technology could adequately prevent applications of excessive force, the grasper tip design interfered with performance, because the tissue slipped relatively easily out of the grip. Ten participants confirmed that the FROI assisted in tissue recognition, diagnosis, and differentiation, but one participant observed no difference compared to the conventional grasper. Nine participants confirmed that the FROI was useful for minimizing tissue damage in human surgery, but one participant did not support this finding, and one participant doubted the relevance. The FROI was perceived to be comfortable for use by six participants, but four participants mentioned that the weight of the grip was a drawback. However, the weight was perceived as less of a problem intra-abdominal, as the trocar eases the weight of the instrument. Ten participants were interested in using the FROI in human surgery. The specific procedures they mentioned included: bowel resection and intestinal handling, pancreatic surgery, retroperitoneal dissection, endometriosis surgery, cystectomy, tubal surgery, radical prostatectomy, total or partial nephrectomy, dividing the renal pedicle, and complex situations in general. Responses were quite ambiguous to the question of the potential learning curve benefits. Three respondents explicitly stated that they expected a shortening of the learning curve; three other respondents interpreted the question in a different way. They stated that haptic feedback would be of significant importance in estimating force applications and appreciating tissue resistance. Four respondents remained undecided. Although it was mentioned that the jaws of the FROI’s grasper tip should be improved, no safety issues were reported, and no safety issues were reported to be anticipated in future use. Overall, nine participants confirmed the clinical relevance of the FROI; one participant did not consider it clinically relevant; and one remained undecided. Additionally, it was mentioned that the effect of the FROI would be particularly interesting in complex procedures.

**Discussion**

This study was conducted to assess the functionality of the FROI compared to a conventional grasper in an in vivo setting. We found that features including tissue consistency sensation and force control were assessed superior for the FROI compared to conventional graspers. Additionally, the FROI enabled arterial pulse detection through haptic perception. No benefits were found for reducing the time to complete surgery or alleviation of muscular strain.
The fact that the FROI was rated superior in subjective tissue recognition compared to the conventional grasper might provide several clinical benefits. As mentioned before, laparoscopic surgery tools drastically reduce haptic feedback compared to open surgery. Briefly, grasping actions are controlled by the central nervous system (CNS). To initiate and correct grasping actions, the CNS sends signals through efferent nerves to execute muscle contractions or relaxations. When we interact with objects, receptors in the skin, muscles, tendons, and joints detect pressure, texture, position, movement, and force, among other sensations. Afferent nerves send these sensory signals to the CNS. The motor control system uses these sensory signals (sensory-motor coupling) to adjust or maintain a grasping action.\textsuperscript{14,15} The principle of sensory-motor coupling substantiates our findings of improved tissue consistency recognition and force control when using enhanced haptic feedback as presented by the FROI.

When a grasping motion is attempted, the sensorimotor system can sense the outcome of that grasping motion and compare it to the desired or predicted outcome. This process is called error-based learning.\textsuperscript{24} When a mechanical grasper does not provide detailed perception through haptic feedback, there is no information to justify a correction (learning) in force application. In the present study, the participating surgeons responded ambiguously, regarding the potential benefit of haptic feedback on the learning curve of laparoscopic surgery. However, Wottawa et al. showed that the implementation of haptic feedback resulted in a significant reduction of force; therefore, haptic feedback enhanced the surgeon’s control over instrument-tissue interaction forces, compared to the conventional (baseline) setting.\textsuperscript{25} However, more research is needed on this topic; e.g., to evaluate retention during a long-term follow-up study or to estimate the number of training hours necessary to increase efficacy in soft-tissue handling.

In the late 1990s, a hybrid surgical procedure was introduced, known as Hand-Assisted Laparoscopic Surgery (HALS). During HALS, one of the (assisting) surgeon’s hands is introduced into the abdomen, next to the laparoscopic trocar, to estimate tissue consistency and to separate tissues. Although we observed variation in the assessments of potential effects on clinical scenarios (Figure 4), several previous studies noted the added value of the intra-abdominal hand, which provided a tactile sense in the procedure.\textsuperscript{26-29} Haptic feedback availability in future laparoscopic instruments will likely increase the number of patients that receive a minimally invasive surgical approach. Consequently, it is expected that the length of hospital stay and post-procedure pain will decrease, and the overall quality of life will improve. Moloo et al. compared the perioperative outcomes of laparoscopic and HALS approaches for colorectal resections. Based on three randomized controlled trials, they found that conversion rates were significantly decreased in patients that underwent HALS.\textsuperscript{30} That finding supported the hypothesis that improved haptic feedback in laparoscopic surgery could also lead to
fewer conversions to open surgery. However, more research is necessary, particularly for surgical procedures that require highly delicate tissue manipulations (e.g., pancreatic surgery or endometriosis surgery), as indicated by the participants of the present study.

Haptic feedback on tissue properties is lost in robotic surgical systems; therefore, the implementation of haptic feedback in robotic surgery might be the next most important development in minimally invasive surgery. A recent experiment demonstrated that the integration of tactile feedback reduced grasping forces and significantly reduced the overall incidence of tissue damage. Additionally, Pacchierotti et al. showed that haptic feedback benefitted palpation and detection. With their add-on tactile sensors in a Da Vinci heart model, they concluded that fingertip deformation feedback significantly improved palpation performance by reducing the task completion time and the pressure exerted on the heart model compared to palpation without haptic feedback. Furthermore, they observed a reduction in the clinician’s absolute error rate during palpation. In the next decade, robotic systems with integrated haptic feedback must prove their value in real operative settings.

Although the majority of participants appraised the overall technology of the FROI as clinically relevant, there were two main design elements that required improvement. First, the grasper tip design was suboptimal during the test. Tips should be adapted in the follow-up version of the FROI to prevent tissue tears, due to slippage, and tissue trauma, due to sharp edged jaws. The FROI is built on platform technology; therefore, at any point in the procedure, it is possible to change the instrument shaft, including the grasper tip, to enable the application of different jaw designs and fenestrations for specific scenarios. The second design element was the weight of the instrument, which was considered heavy compared to the conventional grasper. However, intra-operatively, the trocars reduced the perceived weight. Additionally, the use of an ergonomic pistol grip can distribute the weight of the instrument over the hand to provide stability.

This study had some limitations. First, although the participants in this study were all experts in laparoscopic surgery, the number of participants was rather small. However, the small number was unavoidable, due to the three rules of thumb for the design of animal studies in The Netherlands (substitution, reduction, and refinement). These rules were established to avoid excessive use of animals in experimental studies. Another limitation was that all participants used glove size 7.5 or 8.0; surgeons with either smaller or larger glove sizes might have evaluated the FROI differently. Additionally, the durations of the surgical procedures were short (5 to 15 minutes). The duration might have affected the outcome on the effect of the FROI on muscular strain in the hand and the effect on operation time. Based on previous ergonomics studies on handle designs we hypothesize that the use of the FROI might eventually have an effect on reducing strain in the hand,
particularly in the thenar region. However, objective electromyography studies could be conducted to investigate this hypothesis further. The increase in functionality through enhanced force control and increased tissue consistency sensation suggested that the time to complete surgery might have been reduced; however, this hypothesis can only be validated with future clinical studies in a human, in vivo setting.

In conclusion, this study showed that the FROI approach increased the level of force control, increased the ability to sense and compare tissue consistencies, and enabled the surgeon to detect arterial pulsation. Moreover, we validated the functionality of haptic feedback technology, represented by the FROI, in an in vivo setting. We also elucidated drawbacks that remain to be overcome with the FROI. In future, the value of FROI must be proven in a human operation setting.
References


General discussion
General Discussion

The aim of this thesis was to provide more insight into the physical workload for surgeons involved in minimally invasive surgery. Furthermore, we studied the effects of technological advances on the occupational health of the surgical team and on surgical performance. The second part of this thesis was specifically focused on the development of a new device for haptic feedback in minimally invasive surgery. In this final chapter, reflections on the main results, a summary of our multi-disciplinary approach for surgical instrument development and recommendations for future research are presented.

Gynecologists have traditionally been actively involved in surgical innovations. Apart from performing surgical procedures, gynecologists also perform other tasks including outpatient clinical consultations, work in labor wards, outpatient treatment, education, and administrative work. Most patient-related procedures entail a variety of tasks, which the doctor often performs in an unnatural body position; for example, when performing a vaginal examination with a speculum, assisting in childbirth, and conducting surgery. In Chapter 2, we investigated the prevalence of physical complaints and the presence of ergonomic constraints in Dutch gynecological practice. Surgery was indicated as the most demanding task, followed by working in labor wards and performing outpatient clinical consultations. Although we recognize the importance of considering all working conditions, more detailed examinations of tasks other than surgery were considered outside the scope of this thesis.

The previously reported prevalence rates of physical complaints among gynecological surgeons were consistent with the prevalence rate of 89.4% found in our survey study. Notwithstanding this high prevalence, it was found that more than 90% of respondents were satisfied and proud of their work, which illustrated the high work ethics held by gynecologists. The physician’s job satisfaction is a favorable outcome for patient care, because, in addition to affecting the physician’s personal happiness, it also ensures commitment, service provision, and retention. The saying “happy doctors, happy patients” captures this observation well. Our findings also suggested that gynecological surgeons may regard a high workload as part of the job; indeed, they might consider their own physical fitness of secondary importance to the moral benefit and value of providing patient care. However, to a certain extent, taking care of oneself is a requirement for taking care of patients. Sub-optimal physical fitness in surgeons may affect the quality of surgical care, as it is known from kinesiological studies that both fatigue and physical discomfort can alter routine performance and affect task precision.
Among the general Dutch population, 35.5% of employees report that they work in uncomfortable postures. For employees in health care, this percentage increases to 53%. From European studies, it is known that over 80% of surgeons report that they work in awkward postures, which are, moreover, specifically associated with perceptions of fatigue, discomfort, or pain. Former ergonomic studies have shown that laparoscopic surgery increases the mental stress and physical strain experienced by surgeons. The laparoscopic surgical setup has changed the extent of static workload the surgeon must bear, compared to the conventional open surgical setup. Zooming in on the results of the self-reported posture analysis, shown in Chapter 2, adverse postures were maintained longest specifically in the back (rotation), neck (lateral flexion and rotation of the head), and upper extremities during laparoscopic surgery. In contrast, open surgery is associated with strong flexions of the back and neck. Thus, while adverse postures still affect some of the same parts of the musculoskeletal system, the postures differ. Furthermore, it might also be the increased duration of maintaining specific postures that exceeds personal thresholds for perceiving fatigue or developing musculoskeletal disorders. It was found that, in gynecological surgery the vaginal approach was ergonomically favorable for surgeons, because maintaining adverse body postures was only necessary for short durations. This finding was compatible with the patients’ perspective, because the vaginal approach for a hysterectomy is preferred over the laparoscopic approach and abdominal approach respectively. Consequently, a vaginal hysterectomy could be regarded as minimally invasive from both the patients’ and doctors’ perspectives.

Static workload is measured by summing all the periods that a posture was maintained for four seconds or longer. However, it is highly complicated to determine specific limits of static workloads. Multiple factors must be considered, including the predetermined work-environment, inter-individual differences, and the current extent of scientific knowledge. However, standards have been defined for the maximal acceptable static load. In addition, little attention is focused on the need to vary the types of work and alternate between high and low mentally- or physically-demanding tasks. The physician’s daily schedule is usually fully booked with exclusively surgical procedures or exclusively outpatient consultations. According to the available standards for static workloads, it is acceptable to perform static abduction or anteflexion of the upper arm of more than 20° for only about 96 minutes on a daily basis. The same limit pertains to more than 10° rotation of the trunk. In laparoscopic surgery, these postures are reported to be sustained for significantly long durations. Consequently, the performance of two average minimally invasive surgical procedures may well exceed the standards for the maximum acceptable daily static load. Currently, inconsistent findings have given rise to controversy over whether alternating job tasks would be beneficial for reducing physical workload. However, it has been recommended that a tailored schedule should be designed for specific worksites. Future research should address the question of how job task
alternation could be implemented and, to what extent the implementation might reduce physical complaints.

Over 60% of respondents reported that limited workspace, instruments, and patient size were constraints for adopting a neutral body posture during vaginal, laparoscopic, and abdominal surgery respectively. With the current increases in the number of (morbidly) obese patients, patient size is likely to become a more frequent constraint over the next few decades. Focusing on laparoscopic surgery, several previous studies have pointed out equipment-related constraints that were found in the minimally invasive surgical suite.\textsuperscript{12,22,23} However, in Chapter 2 and Chapter 3, we learned that these constraints continue to remain problematic, despite efforts to resolve equipment issues. First, sub-optimal monitor positioning is associated with neck and back discomfort. Originally, monitors were placed on top of trolleys stacked with other surgical equipment, and positioning options were limited. However, technology has introduced ceiling-mounted monitor arms that have significantly extended the flexibility and range of motion; moreover, the arms allow for quick adjustments. In addition, guidelines for optimal settings during surgery are widely available.\textsuperscript{24,25} More recently, Van Det et al. again emphasized that monitor position in laparoscopic surgery is an important determinant in both the physical workload and in task performance, in terms of both speed and accuracy.\textsuperscript{26} Second, sub-optimal table height is associated with increased shoulder discomfort. This may be due to the fact that the available range of table-height settings is not suitable for relatively short surgeons. Multiple studies have addressed the optimal table height for laparoscopic surgery.\textsuperscript{27-29} Guidelines suggest that the operating surface height should range between a factor of 0.7 and 0.8 of the surgeon's elbow height.\textsuperscript{30} However, when performing surgery on patients with high BMI values, the table should be set at very low levels. Not all operating tables provide such settings; thus, sometimes surgeons must stand on low benches. This situation is not preferable for safety reasons, because often, this places the surgeon next to the foot pedals for coagulation devices. Third, the use of inadequate laparoscopic hand-held instruments commonly leads to physical discomfort in the wrists and hands. Special attention has been paid to the so-called ‘surgeon’s thumb’. This involves pain or discomfort in the thumb, specifically caused by contact pressure induced by the rings of the instrument handle.\textsuperscript{31-33} Almost all laparoscopic handles come with the adage ‘one size fits all’; however, a small hand size is a known risk factor for experiencing physical discomfort and difficulties in using laparoscopic instruments. The most frequently used handle in laparoscopic surgery is the scissors-type handle, with thumb actuation. However, these handles do not sufficiently meet standard ergonomic requirements.\textsuperscript{34,35} All of these findings support the notion that end-users should be involved in the development of equipment used in health-care.
Studies have shown that a majority of surgeons believe that ergonomic guidelines are important in the operation room. In a more contemplative outlook for the future, one might imagine an automatically adjustable personalized surgical suite based on an algorithm that incorporates the surgeons’ anthropometrics and preferences, the specific procedure, and the patient characteristics. In such a way, automotive designers have introduced the functionality of presetting car driver profiles that can automatically adjust for any preference; this profile includes adjustments that range from the seating angle to climate control. On the other hand, introducing surgeon profiles in the OR might come at the expense of causing discomfort to the assistant(s) that work at the same table. Before we reach those futuristic ideals, it is important to commit to ergonomic training and increased awareness of personal physical health, in efforts to provide consistent, high quality surgical care. Correct ergonomics is a learned behavior; surgeons must learn that it is necessary to practice proper posture and postural resetting for a longer, healthier, pain-free surgical career.

In Chapter 3, a few interventions are mentioned that may result in reducing physical workloads. First, formal ergonomic training could be beneficial, as knowledge and awareness of the design of one’s own surgical suite is associated with reducing discomfort. Moreover, ergonomic training was shown to reduce self-reported strain related to robotic surgery, which could in turn improve operation times. Furthermore, warming-up before surgery was proven to improve cognitive, psychomotor, and technical performances. Over the past few years, the effect of (micro)breaks during surgery has been specifically addressed. Engelmann et al. showed that the application of a break scheme which consisted of a five-minute break after every twenty-five minutes of surgery, reduced stress hormone levels in surgeons, reduced intra-operative adverse events, and enhanced post-operative error-performance scores. The break scheme did not prolong the operation time, and moreover, it had no detrimental effect on patient physiology. Dorion and Darveau applied a micro-break pattern, where a 20 second (active) break was taken after every 20 minutes of conventional (open) surgery. They found that this schedule reduced muscle fatigue, lowered the number of physical complaints, and improved accuracy. Moreover, Park et al. found that targeted-stretching micro-breaks could improve the post-procedural pain scores for surgeons in multiple anatomic regions. Finally, it was previously shown that operation durations impacted the perceived workload; therefore, the implementation of micro-breaks could be particularly beneficial in longer procedures. Furthermore, to increase the surgeons’ incentive and willingness to apply (micro)breaks further scientific evaluation is warranted to generate a fitting strategy.
In robot-assisted surgery, the surgeon works in a seated position. Therefore, the robot-assisted approach is presumed to provide more comfort to surgeons than conventional laparoscopic surgery. Although only a limited number of high-quality comparative studies is available, the majority of ergonomic studies have confirmed that robotic-assisted laparoscopy is less strenuous than conventional laparoscopy.\(^4^9\) However, the largest study to investigate specialists in the field of robotic surgery found that, even during robotic surgery, 36% of surgeons experienced discomfort.\(^5^0\) Moreover, another study showed that the prevalence of physical complaints was 72% among surgeons performing robot-assisted surgery.\(^5^1\) In our meta-analysis (Chapter 3), we found that the overall prevalence of physical complaints was 56% among surgeons associated with robotic surgery. It is known that surgeons can benefit by acquiring knowledge regarding personalized ergonomic settings for the robotic setup. Therefore, to ensure the physical well-being of surgeons, it should become routine practice to check the robot console settings prior to surgery.\(^4^0\)

Ambulatory myofeedback systems could be beneficial for reducing the physical workload for surgeons. These feedback systems record muscle activity, and they can emit a visual or audio signal when one of the EMG signals rises above a predetermined level.\(^5^2,5^3\) In addition, a recent study showed that the use of an “alarm-corrected” ergonomic armrest reduced the armrest load score for novices on a robotic simulator.\(^5^4,5^5\) Ideally, these types of feedback systems could be incorporated in residents’ training. This would establish an early career awareness of muscle activity. Additionally, in the robot-assisted surgery setting, it was shown that feedback on the applied grip forces resulted in reductions in both muscle activity and the applied force.\(^5^6\)

In Chapter 4, we deployed an objective approach to determine the physical workload during laparoscopy. With the use of electromyography, it was found that the performance of single-incision laparoscopic surgery (SILS), compared to conventional laparoscopic surgery, resulted in increased muscle loads in the back, neck and shoulder regions. Other studies also found that SILS is mentally and physically more demanding.\(^5^7,5^8\) From an ethical-philosophical perspective, one might question to what extent patients may benefit at the expense of declined ergonomic circumstances for the surgeon.\(^5^9\) The relatively low number of surgeons that embrace SILS may well be due to the inferior ergonomics involved, in addition to the need to learn the skills required for the increased level of difficulty.

In general, we must acknowledge that there are large differences between individuals. Something that is harmful to one surgeon might not be harmful to another surgeon. The occurrences of fatigue and musculoskeletal disorders depend on the ratio between the imposed workload and the individual’s actual physical capacity.\(^6^0\) Thus, we might expect older individuals to be typically more susceptible than younger individuals to...
physical fatigue or musculoskeletal disorders. Conversely, survey studies on surgeons have shown that younger, less-experienced surgeons were more likely than older surgeons to report physical complaints. Therefore, older surgeons might have learned to compensate for stress with experience, and consequently they might experience less strain than younger surgeons. Alternatively, the study by Park et al. indicated that the number of cases performed was more strongly associated with physical complaints than either age or the number of years in practice. Regarding gender, females are more prone to experiencing musculoskeletal disorders. Female surgeons are at a disadvantage compared to male surgeons due to anthropometric differences. In particular, differences in upper body and upper extremities play a significant role in the physical demands of surgery, because the greatest demands are on the back and shoulder musculoskeletal system. Moreover, in general, because women have smaller hands than men, they are at higher risk of developing musculoskeletal disorders in the hands and wrists, due to the fact that most laparoscopic instrument handles come in only one size.

The impact on patient safety was investigated by two Dutch research institutes, The Netherlands institute for Health Services Research (NIVEL) and the Institute for Health and Care Research (EMGO+). They studied the annual prevalence of potentially avoidable care-related harmful events in The Netherlands between April, 2015 and March 2016. Overall, 33% of care-related harmful events were related to medication, and 29% of events were related to surgical procedures. Half of the surgery-related events involved potentially avoidable damage. Strikingly, all of these potentially avoidable damages ended in death. These damages mainly involved complications, due to infections, perforations, bleeding, and prolonged procedures. Among the potentially avoidable damages in which medical technology played a role, the damages were not strictly caused by the technology; instead, they resulted from negligence or incompetence in the use of the technology. That finding stressed the importance of acquiring both the technical knowledge and the accompanying skills.

The market for minimally invasive surgical instruments is rapidly growing, and the market is saturated with competing companies. Nearly every company has its own models of basic surgical instruments. Currently, the number of innovations brought to market is increasing, although most are actually derivatives of basic instruments. In addition, surgical products are being pushed their way up to their users nowadays, which then prompts surgeons to analyze their daily practice frequently. On the other hand, surgeons have their own professional pride and confidence. Not surprisingly, there is some skepticism in implementing new ideas and technologies. Moreover, skepticism is reinforced when companies state “previous methods are not ideal; we have a better way.” However, unjustified skepticism might affect the successful implementation of new technologies that might optimize the quality of surgical care. Nevertheless, a
healthy dose of skepticism regarding new technologies among surgeons might promote improvements in the quality of surgical care, due to the regular critical appraisal of new products. It is important to ensure that new technologies have a sound rationale, are well validated, and thus, are based on solid scientific evidence.69-71

The development trajectory of a laparoscopic grasper with implemented haptic feedback, the Force Reflecting Operation Instrument (FROI), originated from a clinical need: laparoscopic surgeons who experienced the lack of feedback on tissue properties in minimally invasive surgery and who feared the potential impact on surgical safety. Experimental studies and literature reviews have highlighted the potential benefits of implementing haptic feedback in laparoscopic graspers.72,73 Previous experimental studies had shown that the residual amount of haptic feedback on tissue properties that can be perceived with conventional laparoscopic graspers on tissue properties lacked clinical relevance.74,75 Moreover, conventional graspers induce a significant greater force application than that is actually required to hold tissue.76,77 Additionally, it was noted that visual misperceptions might occasionally cause adverse events during surgery that may lead to either intra- or post-operative complications. Overall, it is concluded that enhanced haptic feedback could benefit surgical quality and safety. Chapter 5 illustrates the clinical support from laparoscopic surgeons for the implementation of haptic feedback. Additionally, the onset of the development of a new instrument is a great opportunity to tackle pre-existing issues like instrument-handle design. We solicited expert opinions regarding current handle designs for laparoscopic graspers. Overall, 77% of surgeons reported physical complaints that were directly attributable to the use of laparoscopic instruments. Moreover, contact pressure was frequently experienced in the thumb and thenar areas. Consistent with the existing literature, this is again an urgent call for the re-design of instrument handles. Specifically, a pistol handle might meet the need to alleviate contact stress during instrument control.78,79

Many research and development teams have addressed the challenge of improving hand-tool-tissue interaction to enhance the sense of touch in laparoscopy. Different approaches have been investigated, including developing separate probing devices or adding sensors to the instrument jaws. Furthermore, different ways of presenting tissue information to surgeons have been developed, including visual, haptic, or auditory feedback.80 One prototype grasper that was recently developed incorporated the tactile component of haptic feedback by both a rotating cylinder, to perceive pending slippage, and vibration patches, to perceive excessive force application.81 Also, in robot-assisted surgery, pneumatic balloons were recently developed, specifically to restore the tactile component of haptic feedback.82 The FROI provides both tactile and kinesthetic components in an intuitive way. The surgeon moves the instrument lever to open and close the instrument jaws. When the tissue is grasped between the instrument jaws, the tissue is compressed,
and a corresponding amount of resistance is perceived by the surgeon as tactile feedback due to increased pressure on the fingertips touching the lever of the grip. By an increasing or decreasing level of resistance (i.e. opening or closing the grasper while in contact with the tissue) kinesthetic feedback is perceived by the acceleration and deceleration effectuated in the movement of the fingers as well as a change in joint position. Haptic feedback in current instruments almost solely originates from movement towards a firmly closed grasp, with negligible nuances of acceleration and deceleration that correspond to tissue consistencies. The most ideal and intuitive way of providing haptic feedback in laparoscopic instruments has to be established in future well-designed studies.

The validity of the FROI was investigated through an iterative design approach, which involved close cooperation between technicians, clinicians, and intermediaries. The technological development of this instrument involved specific mechatronics expertise, but the technological efforts, product specifications, and recommendations in the development of the FROI are outside the scope of this thesis. As a consequence, in the conduct of validation studies, the research team was dependent on the technological progress and moreover availability of instrumentation. The overall aim of developing the FROI involved the restoration of accurate information on forces applied on the tissue and to facilitate optimal hand-tool-tissue interaction. Five specific determinants were formulated to investigate the validity of the FROI including: tissue consistency sensation, arterial pulse detection, force control, time efficiency, and hand-grip comfort.

As presented in Chapter 6, the FROI technology provided significantly improved tissue consistency sensation combined with a significant reduction in force application. These findings are of utmost importance, to perform a safe grasping action that prevents the occurrence of tissue damage including perforations, tears or tissue necrosis. Tissue consistency sensation might well have a beneficial clinical impact in several surgical indications. For example, in laparoscopic ovarian cystectomy, sensing the tissue consistency might allow surgeons to feel the difference between normal and abnormal tissues. In patients with a suspected malignancy, tissue properties sometimes inform the surgeon in deciding whether to take samples. Moreover, it was demonstrated in experimental settings and in the in vivo setting (Chapter 7) that delicate arterial pulses could be detected solely through the use of haptic feedback. The validation of these features might eventually contribute to the efficiency of laparoscopic surgical procedures and reduce the time necessary to complete a procedure.

Hand-assisted laparoscopic surgery (HALS) has been shown to obviate the need to convert to open surgery (e.g., in cases where a delicate palpation of the bowel is indicated). Additionally, HALS could reduce the time to complete surgery for specific procedures. However, the HALS approach was never widely adopted, mainly due to the difficulty in
maintaining pneumoperitoneum (because the hand has to be inserted through a plastic ring to reach into the abdominal cavity) and the inferior cosmetic results compared to standard laparoscopy. However, the availability of all three key features of the FROI (force control, tissue consistency recognition, and arterial pulse detection) might enable surgeons to complete procedures with the laparoscopic approach, when currently still the open abdominal approach is chosen. Arterial pulse detection could facilitate a targeted arterial approach or prevent accidental dissection of arteries that are hidden within structures.

The functional features of the FROI were validated in an experimental setting. Chapter 7 focuses on the functionality of these features in an in-vivo setting. The improved soft tissue handling was acknowledged by experts. Also the importance for complex procedures like tubal re-anastomosis surgery or partial nephrectomy was expressed. However, the results should be interpreted with caution because an objective measurement of force application was not possible in this study. Furthermore, it remains to be determined what role haptic feedback might play in the teaching setting. All this information should be gathered in future studies.

Finally, expert surgeons might think and expect that they actually perceive haptic feedback from tissues through conventional instruments, but this is not really the case. This is mainly the result from visual clues that are interpreted as haptic information. Sometimes innovations can fulfill an unrealized unmet need. That is to say, sometimes one can only understand the added value of something, once they finally use it or once the product has become widely available. This phenomenon was put succinctly in the famous phrase that was supposedly said by Henry Ford: “If I had asked the people what they wanted, they would have said faster horses”. Typically, the decision of whether to use a product is based on the balance of multiple factors, including, but not limited to, efficacy, efficiency, usability, safety, learning curves and costs. Considering alternative options that are slightly different (e.g., faster horses) is only a matter of iteration towards sufficiency and satisfaction. However, true innovation, in terms of new products, can induce complete reconsiderations of the factors on the balance. When other manufacturers appeared on the market, Ford’s new goal was to make cars accessible and affordable to common people. Indeed, it was eventually the assembly line that made him a revolutionary industrialist. Lowering the cost of cars revised the balance of factors, and made it easier for more people to buy a car. Clearly, a car was something people wanted, and once it became affordable, it was widely adopted. In the case of the unrealized need of haptic feedback in minimally invasive surgery, even though pre-clinical evidence has demonstrated the benefits of haptic feedback, target users may believe that their own methods are perfectly acceptable. Since some complications like bowel perforation or heavy bleeding are rare, large studies are needed to prove any potential effect. Until that time, skepticism will possibly lead to a delay in clinical implementation.
The overall development and validation of the FROI follows the path of what is in our eyes an optimal path for development of new surgical instruments. To start, there was a clinical question and hypothesis. End-users, in this case surgeons, co-developed a prototype with technicians, designers, and ergonomists. The prototype was then tested with a box-trainer simulation task. Based on these experiences, new features were added to the prototype or suboptimal characteristics were improved. This cycle continued until no items remained to be resolved. Next, in-vivo testing was performed in a valid animal model. Experts used the instrument extensively and provided critical feedback on the expected benefits. Alongside this path, the required pathway for certification and approval for in-patient use is followed. Post-market surveillance and further in-vivo studies will have to evaluate the expected benefits on the basis of the previous tests following the IDEAL model. This model is a method for improving the quality of research in surgery following the stages: innovation, development, exploration, assessment, and long-term follow up. In this way, the introduction of new technology in health care can contribute to the improvement of quality of care without impairing patient safety or surgical ergonomics.

**Topics for future research.**

Following this thesis, the next items remain interesting topics for future research:

- To develop an optimal daily working-schedule for surgeons from both economic and ergonomic perspectives.
- To further implement ergonomic guidelines in the field of minimally invasive surgery; for surgical residents, these guidelines should be an integrated part of the learning objectives in laparoscopy courses.
- To evaluate interventions, such as microbreaks or active rest breaks, and determine the effects on the surgeons’ physical discomfort during laparoscopic surgery, preferably in a randomized clinical trial.
- To analyze and develop an optimal design for laparoscopic instrument handles by means of EMG, ideally in a setting where developers and end-users cooperate to create a handle with maximum comfort for surgeons.
- To evaluate the potential benefits of haptic feedback in laparoscopic surgery in the human setting, with specific focus on its effects on tissue damage, patient recovery, and surgeons’ physical discomfort.
- To study the role and added value of haptic feedback in robot-assisted surgery.
- To develop a blueprint for a multidisciplinary approach with a clinically driven character for surgical instrument design in the early, pre-clinical innovation phase.
- To develop guidelines for bringing new surgical instruments to the market and to evaluate these guidelines.
References


9

Summary
Samenvatting
Summary

The introduction of minimally invasive surgery (MIS) has brought many benefits for patients. Surgeons however, are burdened with increased physical demands imposed by ergonomic constraints in the surgical suite. This matter is globally explained in Chapter 1. After the first commended laparoscopic cholecystectomy (removal of the gallbladder) in 1985, studies have proven the patients’ benefits of laparoscopic surgery over conventional (open) surgery. Among these are faster recovery, shorter hospital stay, less postoperative pain, and improved cosmetic results. In contrast to these patient benefits, the laparoscopic surgical approach imposes limitations for surgeons including: equipment and instrument-control restrictions, loss of direct vision and direct haptic feedback. As a consequence of these limitations surgeons are exposed to multiple risk factors for developing musculoskeletal disorders (MSDs). Indeed, alarmingly high prevalence rates of surgery related MSDs have been reported. Zooming in on the usability of laparoscopic graspers, they typically fall short when it comes to translating key information on tissue properties to the surgeon. Haptic feedback should enable the surgeon to perceive information on interaction forces between instrument and tissue through the instrument handle in order to accurately control their applied grip forces and to sense tissue consistencies. Through ergonomic studies, surgical tasks, equipment, and the environment can be evaluated and (re-)designed in order to make them compatible with the needs, abilities and limitations of surgeons. The first part of this thesis addresses the physical workload in minimally invasive surgery and the impact on the physical well-being of surgeons. The second part of this thesis is dedicated to user-centred instrument design and the validation of a laparoscopic grasper with integrated haptic feedback.

The aim of the study presented in Chapter 2 was to investigate the prevalence of physical complaints and the presence of ergonomic constraints in Dutch gynecological practice. To address this aim, a questionnaire was distributed among the 1200 members of the Dutch Society of Obstetrics and Gynecology. A total of 227 respondents completed this questionnaire (response rate 18.9%). Overall, 99.5% of these respondents rated their health status as reasonable or good. In contrast, the twelve-month prevalence of physical complaints in one or more body part was 89.4%. While strong flexion of the neck and trunk were reported in open surgery, exposure to risk factors including lateral flexion of the neck, trunk rotation and raised shoulders and elevated upper arms were reported in laparoscopic surgery. Sustained adverse postures were particularly reported for performing laparoscopic surgery, and for assisting in vaginal surgery. Limited workspace, instruments and patient size were reported by more than 60% of the respondents as constraints for adopting a neutral body posture during vaginal, laparoscopic and abdominal surgery respectively. The results of this study emphasize the necessity of enhancing ergonomics in gynecological daily practice. Better ergonomic circumstances will most likely benefit both the health of the gynecologist as well as the quality of surgical care.
Several studies have addressed the physical burden of minimally invasive surgery and the occupational health hazards for surgeons in different specialties. In Chapter 3 we present a systematic review of the literature on the prevalence of MSDs among surgeons performing minimally invasive abdominal surgery. It was aimed to identify all studies that addressed physical ergonomics as a determinant, reported the prevalence of MSDs (or physical complaints) as a study outcome, and were published as full-text articles in a peer-reviewed journal. Thirty-five articles were identified. From a dataset including 7112 surgical specialists, a meta-analysis revealed an overall prevalence of physical complaints among laparoscopic surgeons of 74%. Based on this outcome, we might well speak here of a silent epidemic, which has also been emphasized in an accompanied editorial in Annals of Surgery by Dr. Adrian Park. Since a prevalence of 74% is alarmingly high, this systematic review warrants future well-designed survey studies, since the meta-analysis was subject to studies with low response rates and rather high inconsistency across studies.

In Chapter 4, the results of a randomized controlled trial on the physical workload of surgeons during single-incision laparoscopic surgery (SILS) and conventional laparoscopic surgery (CLS) are presented. Because in SILS only one incision is made instead of the three to five, as in CLS, it is claimed that the SILS technique further reduces discomfort and pain in patients. Yet, upon the introduction of SILS hardly anything was known about the impact on the physical well-being of surgeons. While performing surgical tasks in a simulation setting, the muscle activity of ten surgeons was measured through electromyography. Eight muscles of the trunk and upper extremities were measured bilaterally. Significantly higher muscle activity in the musculus (m.) longissimus, m. trapezius pars descendens, and the m. deltoideus pars clavicularis was detected during SILS compared to CLS. These findings are consistent with the cross-hand technique that is used in SILS, a technique that further restricts the surgeon's static posture compared to CLS. The increased level of muscle activity found during SILS could result in an earlier surpass of the comfort limit of a surgeon compared to CLS. In conclusion, it was objectively shown that, performing SILS increases the physical demand of surgeons in the back, neck and shoulder region.

The main problems with laparoscopic graspers include sub-optimal ergonomics and lack of haptic feedback. From the start, the involvement of end users in the design process of new products is indispensable for suitability, safety, and acceptance. Through the survey study presented in Chapter 5, soundings were taken among a multispeciality group of laparoscopic surgeons based in Europe. The objective of this study was to find out surgeons' opinions regarding handle design of currently used laparoscopic graspers, and the clinical interest for enhanced haptic feedback. From the 279 contacted surgeons, 98 completed the questionnaire (response rate 35%). Of all respondents, 77% reported physical complaints directly attributable to the use of laparoscopic instruments.
Furthermore, discomfort due to excessive local pressure, or friction between instrument and hand were frequently reported. Besides the design of the instruments, also the potential impact of haptic feedback was questioned. The pre-determined potential benefits of enhanced haptic feedback include: feeling differences in tissue consistencies, feeling how much pressure is applied, locating a tumor or enlarged lymph node, detecting arterial pulse, and limiting the strain in the surgeons hand. Surgeons of different disciplines recognize the need for haptic feedback and the aforementioned associated potential benefits. Other pre-determined potential effects of haptic feedback implementation, including: lowering the time to complete surgery, reducing complications, reducing conversions to open surgery and performing laparoscopy instead of open surgery were not convincingly supported by the respondents. Based on the results of the questionnaire, we hypothesized that haptic feedback is an unmet need in laparoscopic surgery. Along with the development of a haptic feedback grasper, the potential benefits should be examined in (pre-)clinical experimental research.

A prototype laparoscopic grasper with enhanced haptic feedback was developed, called the force reflecting operation instrument (FROI). By using "Optical fiber bragg grating" technology, this instrument is capable of measuring the interaction forces between the grasped tissue and the instrument jaws and transmits this information to the surgeon through a resistance mechanism in the instrument handle. In Chapter 6, the effects of enhanced haptic feedback on force control, tissue consistency interpretation, and associated surgeons level of confidence in the latter was investigated through a randomized controlled crossover experiment. Fresh slices of porcine organ tissue (lung, small intestine and liver) were presented in a laparoscopic box trainer. While visual feedback on instrument-tissue interaction was eliminated, all twenty participants were requested to palpate tissue with three different graspers: the FROI with enhanced haptic feedback activated, the FROI with enhanced haptic feedback deactivated and a conventional grasper. Participants compared tissue consistencies through tissue manipulation and the applied grasping forces were registered. It was found that the applied forces significantly decreased with a factor 3.1 as a result of the availability of haptic feedback. Additionally, tissue consistency interpretation was significantly improved and participants decided with significantly more confidence when enhanced haptic feedback was available. These findings support the hypothesis that enhancing haptic feedback may increase the usability of laparoscopic graspers and could have multiple important clinical implications, such as less tissue trauma, fewer complications and a reduction in operation time.

After completion of simulation studies to optimize the settings of the FROI and redesign the instrument handle, a randomized two-period crossover trial was conducted to study the functionality of the FROI in an in-vivo porcine setting (Chapter 7). Eleven laparoscopic experts performed paired colorectal, gynecological, or urological procedures, once with
the FROI and once with a conventional grasper. The performance of the FROI was assessed through questionnaires. Tissue consistency sensation and force control were subjectively assessed and considered superior for the FROI compared to conventional graspers. Additionally, the FROI enabled the surgeons to detect arterial pulse through haptic perception. No significant effects were reported for muscular strain or operation time. The surgeons especially highlighted improved soft tissue handling and the clinical value for complex procedures. In conclusion, although two main design elements required improvement (the grasper tip design and the weight of the instrument) the functionality of haptic feedback technology, represented by the FROI, in an in-vivo setting was validated.

In Chapter 8 reflections on the main results of this thesis and recommendations for future research were presented. Since the indications for laparoscopic surgery over open surgery continue to broaden, the 74% prevalence of MSDs among surgeons performing minimally invasive surgery found in our systematic review is alarmingly high. Greater focus on improving surgical ergonomics is warranted and may eventually contribute to the overall goal to ever improving the quality of surgical care. Former studies have indicated equipment related constraints, and some advances in the usability of instruments and equipment have been introduced. However, even when improvements are available nowadays, risk factors for developing MSDs remain present. While robot-assisted surgery propagates superior ergonomics due to the ability to operate from a seated position, it still remains to be investigated if the robot-assisted approach in the long term contributes to a decrease in MSD prevalence. Methods to reduce strain in conventional laparoscopic surgery could be the implementation of formal ergonomic training in the residents curriculum or the implementation of tailored work schedules that alter job tasks. However, the effect of these ideas should be investigated. Warming-up before surgery, implementing micro-breaks and implementing myofeedback seem to be promising interventions, however also here additional research is necessary. Moreover, end-users should be involved in the development of equipment for health-care purposes and improvement is required to guarantee usability and comfort. Such a clinically driven approach was followed in the development of the Force Reflecting Operation Instrument. Through extensive testing and following an iterative design approach generating multiple prototypes, the FROI technology was validated for improving force control, tissue consistency estimation and arterial pulse detection in both simulation setting and a porcine in-vivo setting. This multi-disciplinary approach with a clinically driven character to new technology in minimally invasive surgery will likely benefit both patients and surgeons.
Samenvatting

De introductie van minimaal invasieve chirurgie (laparoscopie) heeft veel voordelen opgeleverd voor patiënten. Chirurgen kregen echter te maken met een toegenomen fysieke belasting door ergonomische knelpunten in de operatiekamer. Deze situatie wordt globaal uiteengezet in Hoofdstuk 1. Nadat de eerste laparoscopische verwijdering van de galblaas werd uitgevoerd in 1985, hebben vele onderzoeken de voordelen van laparoscopische chirurgie voor patiënten ten opzichte van conventionele (open) chirurgie aangetoond. Hiertoe behoren een sneller herstel, kortere ziekenhuisopname, minder postoperatieve pijn en betere cosmetische resultaten. In tegenstelling tot deze voordelen voor de patiënt legt laparoscopie de chirurgen echter een aantal beperkingen op, waaronder: beperkte controle over apparatuurinstellingen en een bemoeilijkte bediening van instrumenten, verlies van het directe zicht op en de directe aanraking van het weefsel. Als gevolg van deze beperkingen worden chirurgen blootgesteld aan meerdere risicofactoren voor het ontwikkelen van klachten aan het bewegingsapparaat (musculoskeletale aandoeningen; MSA). Er zijn alarmerend hoge prevalentiecijfers van MSA onder chirurgen gerapporteerd. Als we verder inzoomen op de gebruiksvriendelijkheid van laparoscopische paktangen, zien we dat deze meestal tekort schieten als het gaat om het overbrengen van belangrijke informatie over weefseleigenschappen naar de chirurg. Haptische feedback zou de chirurg in staat moeten stellen om informatie over interactiekrachten tussen het instrument en het te manipuleren weefsel waar te nemen via het handvat van het instrument. Dit zou dan met name dienen om de toegepaste grijpkrachten nauwkeurig te doseren en om weefselconsistenties te onderscheiden. Door middel van ergonomisch onderzoek kunnen chirurgische werkzaamheden, de apparatuur, instrumenten en de omgeving worden geëvalueerd en (her)ontworpen om deze af te stemmen op de behoeften, de mogelijkheden en de beperkingen van chirurgen. Het eerste deel van dit proefschrift behandelt de fysieke belasting bij laparoscopische chirurgie en de impact op het fysieke welzijn van chirurgen. Het tweede deel van dit proefschrift gaat over het ontwikkelen van een nieuw instrument volgens de principes van “user centered instrument design” en de validatie van een laparoscopische paktang met geïntegreerde haptische feedback.

Het doel van de studie gepresenteerd in Hoofdstuk 2 was om de prevalentie van fysieke klachten en de aanwezigheid van ergonomische knelpunten in de gynaecologische praktijk te onderzoeken. Om dit doel te bereiken werd een vragenlijst uitgezet naar de 1200 leden van de Nederlandse Vereniging voor Obstetrie en Gyneecologie. In totaal vulden 227 respondenten deze vragenlijst in (respons 18,9%). Van deze respondenten beoordeelden 99,5% hun gezondheidsstatus als redelijk of goed. Daarentegen was de 12-maanden prevalentie van klachten aan het bewegingsapparaat 89,4%. Daar waar met name een sterke flexie van de nek en het bovenlichaam werden geassocieerd met open
chirurgie, werden sterke laterale flexie van de nek en romp, opgeheven schouders en zijwaartse geheven bovenarmen geassocieerd met laparoscopische chirurgie. Beperkte werkruimte, suboptimale instrumenten en de lichaamsomvang van de patiënt werden door meer dan 60% van de respondenten aangegeven als knelpunten voor het aannemen van een neutrale lichaamshouding tijdens respectievelijk vaginale, laparoscopische en abdominale chirurgie. De resultaten van deze studie benadrukken de noodzaak om de ergonomie in de gynaecologische praktijk te optimaliseren. Betere werkomstandigheden zullen hoogstwaarschijnlijk zowel de gezondheid van de gynaecoloog als de kwaliteit van de chirurgische zorg bevorderen.

Verschillende studies hebben de fysieke belasting van minimaal invasieve chirurgie en de gevaren voor de fysieke gezondheid van chirurgen binnen verschillende specialismen in kaart gebracht. In Hoofdstuk 3 presenteren we een systematisch literatuuronderzoek over de prevalentie van MSA bij chirurgen die gespecialiseerd zijn in laparoscopie. Het doel van dit onderzoek was om alle studies te identificeren die gericht waren op de fysieke ergonomie en die de prevalentie van MSA rapporteerden als een studieresultaat. Tevens was het een voorwaarde dat de artikelen waren gepubliceerd in een peer-reviewed tijdschrift. In totaal werden 35 artikelen geïdentificeerd. Uit de daaruit verkregen dataset van 7112 chirurgische specialisten bleek de algemene prevalentie van lichamelijke klachten 74% te zijn. Op basis van deze uitkomst kunnen we voorzichtig spreken van een stille epidemic. Dit werd tevens benadrukt in de begeleidende editorial bij ons literatuuronderzoek in Annals of Surgery door Dr. Adrian Park. Tot slot toont dit literatuuronderzoek de noodzaak aan voor additionele, goed ontworpen studies; in het bijzonder omdat de meta-analyse afhankelijk was van vragenlijstonderzoeken met lage responspercentages en vrij hoge inconsistenties tussen deze onderzoeken.

In Hoofdstuk 4 worden de resultaten gepresenteerd van een gerandomiseerde studie naar de fysieke belasting van chirurgen tijdens laparoscopische chirurgie met een enkele incisie (SILS) en conventionele laparoscopische chirurgie (CLS). Omdat bij SILS slechts één incisie wordt gemaakt in plaats van de drie tot vijf zoals bij CLS, is het aannemelijk dat de SILS-methode het ongemak en de pijn bij patiënten vermindert. Echter, bij de introductie van SILS was nauwelijks iets bekend over de impact op het fysieke welzijn van chirurgen. In onze studie werd tijdens het uitvoeren van chirurgische taken in een simulatieomgeving de spieractiviteit bij tien chirurgen gemeten door middel van electromyografie (EMG). Acht spieren van de romp en de bovenste extremiteiten werden bilateraal gemeten. Er werd een significant hogere spieractiviteit in de musculus (m.) longissimus, m. trapezius pars descendens, en de m. deltoideus pars clavicularis gedetecteerd tijdens SILS in vergelijking met CLS. Dit sluit aan bij de uitvoering van SILS, waarbij voor de bediening van de instrumenten de chirurg zijn onderarmen over elkaar kruist. Deze techniek beperkt de statische houding van de chirurgen in toenemende mate in vergelijking met CLS.
Het verhoogde niveau van spieractiviteit tijdens SILS kan resulteren in een eerdere overschrijding van de comfortlimiet van een chirurg in vergelijking met CLS. Concluderend werd objectief aangetoond dat het uitvoeren van SILS de fysieke belasting van chirurgen in de rug-, nek- en schouderregio doet toenemen.

De belangrijkste problemen met laparoscopische paktangen zijn de suboptimale ergonomie en het gebrek aan haptische feedback. Wanneer men nieuwe producten wil gaan ontwikkelen is de betrokkenheid van eindgebruikers bij het ontwerpproces onmisbaar voor gebruiksvriendelijkheid, veiligheid en acceptatie. Door middel van het in Hoofdstuk 5 gepresenteerde vragenlijstonderzoek werd een peiling uitgevoerd onder een groep Europese chirurgen gespecialiseerd in verschillende disciplines binnen de laparoscopie. Het doel van deze studie was om de standpunten van chirurgen over het ontwerp van de handvatten van heden ten dage veelgebruikte laparoscopische paktangen te achterhalen. Daarnaast werden opvattingen en verwachtingen ten aanzien van de vermeende klinische relevantie voor verbeterde haptische feedback ondervraagd. Van de 279 benaderde chirurgen hebben er 98 de vragenlijst ingevuld (respons 35%). Van alle respondenten rapporteerde 77% fysieke klachten die zij direct toeschreven aan het gebruik van laparoscopische instrumenten. Bovendien werd ongemak ten gevolge van overmatig lokale druk of wrijving tussen instrument en hand frequent gerapporteerd.

Naast het ontwerp van de instrumenten werd ook de potentiële impact van haptische feedback bevraagd. De vooraf vastgestelde potentiële voordelen van het integreren van haptische feedback in laparoscopische paktangen betroffen: het verschil kunnen voelen in weefselconsistenties, voelen hoeveel knijpkracht er wordt uitgeoefend, lokaliseren van een tumor of vergrote lymfeklier, arteriële pulsatie detecteren en de spierbelasting in de hand van de chirurgen beperken. De deelnemend chirurgen erkenden veelal de noodzaak van haptische feedback en de bovengenoemde potentiële voordelen. Andere vooraf vastgestelde potentiële effecten van implementatie van haptische feedback, waaronder: het reduceren van de tijd om een operatie te voltooien, het verminderen van complicaties, het verminderen van conversies naar open chirurgie en het uitvoeren van laparoscopie in plaats van open chirurgie, werden niet overtuigend ondersteund door de respondenten.

Op basis van de resultaten van deze studie stelden we de hypothese dat haptische feedback een nog onvervreemde behoefte is bij laparoscopische chirurgie. Gedurende de ontwikkeling van een paktang met geïntegreerde haptische feedback, zouden de potentiële voordelen moeten worden onderzocht in (pre-)klinisch experimenteel onderzoek.

Er werd een prototype van een laparoscopische paktang met geïntegreerde haptische feedback ontwikkeld, het “Force Reflecting Operation Instrument” (FROI). Door gebruik te maken van speciale glasvezeltechnologie kan dit instrument de interactiekracraken meten tussen het vastgegrepen weefsel en het bekje van het instrument en deze informatie vervolgens doorgeven aan de chirurg via een weerstandsmachemie in de handgreep.
van de paktang. In Hoofdstuk 6 werden de effecten van versterkte haptische feedback op krachtcontrole, interpretatie van de weefselconsistentie en het niveau van vertrouwen op de eigen haptische waarneming onderzocht met behulp van een gerandomiseerd experiment. Verse plakjes orgaanweefsel van varken (leng, dunne darm en lever) werden gepresenteerd in een laparoscopische boxtrainer. Visuele feedback op instrument-weefsel interactie was uitgesloten. Alle twintig deelnemers werden verzocht om weefsel te palperen met drie verschillende grijpers: de FROI (met haptische feedback-technologie) geactiveerd, de FROI gedeactiveerd en een conventionele paktang. Deelnemers vergeleken de weefselconsistenties door weefselpalpatie middels de verschillende tangen. Tegelijkertijd werden de grijpkrachten die daarvoor werden toegepast geregistreerd. Het bleek dat de toegepaste krachten gemiddeld met een factor 3.1 afnamen ten gevolge van de beschikbaarheid van haptische feedback. Bovendien werd de interpretatie van weefselconsistentie significant verbeterd en deelnemers hadden significant meer vertrouwen in hun bevindingen wanneer versterkte haptische feedback beschikbaar was. Deze resultaten ondersteunen de veronderstelling dat het verbeteren van haptische feedback de gebruikersvriendelijkheid en functionaliteit van laparoscopische grijpers kan vergroten. Dit kan klinisch belangrijke implicaties hebben, zoals minder weefseltrauma, minder complicaties en een kortere operatietijd.

Na het voltooien van simulatieonderzoeken om de instellingen van de FROI te optimaliseren en nadat het handvat van de FROI was herontwikkeld, werd een dierexperimenteel onderzoek uitgevoerd om de functionaliteit van de FROI in een in vivo omgeving te bestuderen (Hoofdstuk 7). Elf laparoscopische experts voerden gepaarde colorectale, gynaecologische of urologische procedures uit. In gerandomiseerde volgorde verrichten ze deze één keer met de FROI en één keer met een conventionele paktang. De subjectieve prestaties van de FROI werden beoordeeld door middel van vragenlijsten. Waarneming van weefselconsistentie en krachtcontrole werden als superieur beschouwd voor de FROI in vergelijking met conventionele paktangen. Bovendien stelde de FROI de chirurgen in staat arteriële pulsaties op de tast te detecteren. Er werden door de deelnemers geen significante effecten verwacht voor spierbelasting of operatietijd. De chirurgen benadrukten vooral de verbeterde hantering van zachte weefsels en de toegevoegde waarde voor complexe procedures. De functionaliteit van haptische feedbacktechnologie van de FROI werd in deze in vivo omgeving valide bevonden. Er werden echter tevens twee belangrijke ontwerpelementen gevonden die verbetering vereisten, namelijk het ontwerp van het bekje van de paktang en het gewicht van het instrument.

In Hoofdstuk 8 worden de belangrijkste resultaten van dit proefschrift nader bediscussieerd en aanbevelingen voor toekomstig onderzoek gepresenteerd. Omdat de indicaties voor laparoscopische chirurgie blijven toenemen, is de gevonden prevalentie van klachten aan het bewegingsapparaat bij chirurgen die minimaal invasieve chirurgie uitvoeren schrik-
barend hoog. Meer aandacht voor het verbeteren van de ergonomie van laparoscopische chirurgie is noodzakelijk en kan uiteindelijk bijdragen aan het algemene doel om de kwaliteit van chirurgische zorg te verbeteren. Eerdere studies hebben reeds gewezen op de knelpunten in de werkomgeving van de chirurg en enkele verbeteringen in de bruikbaarheid van laparoscopische instrumenten zijn geïntroduceerd. Maar ook met deze verbeteringen blijven risicofactoren voor de ontwikkeling van fysieke klachten bestaan. Hoewel robot-geassisteerde chirurgie superieure ergonomie claimt vanwege de zittende positie die de chirurg aanneemt om te opereren, moet nog worden onderzocht of deze robot-geassisteerde aanpak op lange termijn bijdraagt aan een afname van MSA-prevalentie.

Een aantal mogelijke verbeteringen in de werkomgeving voor minimaal invasief werkende chirurgen wordt besproken. Hoewel het effect van deze interventies nog uitgebreider moet worden onderzocht, lijken deze methoden de belasting bij laparoscopische chirurgie gedeeltelijk te kunnen terughalen. Een belangrijke factor is de implementatie van ergonomiche training in het opleidingscurriculum van snijdende specialismen en de implementatie van aangepaste werkschema’s die ervoor zorgen dat taken worden afgewisseld. Ook warming-up voorafgaand aan de operatie, het invoeren van (micro)pauzes en het implementeren van myofeedback lijken veelbelovende interventies te zijn. Bovendien moeten eindgebruikers worden betrokken bij de ontwikkeling van nieuwe producten en is verbetering van het huidige instrumentarium vereist om de bruikbaarheid en het comfort te garanderen. Een dergelijke klinisch gestuurde aanpak werd gevolgd bij de ontwikkeling van het FROI. Door uitgebreide testen en het volgen van een iteratieve ontwerpbenadering die meerdere prototypen heeft gegenereerd, werd de haptische feedback-technologie van het FROI gevalideerd voor het verbeteren van krachtcontrole, de schatting van weefselconsistentie en de detectie van arteriële pulsaties in zowel simulatie-opstellingen als het in vivo varkensmodel. Deze multidisciplinaire aanpak met een klinisch gestuurd karakter voor de ontwikkeling van nieuwe technologie bij minimaal invasieve chirurgie zal waarschijnlijk zowel de patiënten als de chirurgen ten goede komen.
Addendum

“Physician heal thyself” isn’t working

Editorial by Adrian Park, MD

Annals of surgery 2017;266(6):921-922

Printed with permission
Surgeons, as leaders and colleagues of surgeons will attest, complain about many things. Singularly absent on the list of things we complain about is the topic of ourselves. There are likely 2 reasons behind this: one is a basic altruism, a sense of duty, deeply ingrained that surgeons will do whatever it takes to ensure the best outcomes for their patients. The other is that it has never felt appropriate or safe to do otherwise. To admit that you are not well might be construed as a sign of weakness. It might also spark a lack of confidence and certainly a fear of abandonment by one’s referring sources. So, most surgeons soldier on keeping their suffering to themselves. It has become increasingly evident that surgeons and many other species of physicians are not as healthy and well as they should be. It has only recently become acceptable to discuss issues of surgeon and physician mental and physical well-being. A relatively recent but rapidly growing literature speaks to the alarming rate of burnout among physicians. Burnout is a well-defined syndrome of emotional exhaustion, depersonalization, and feeling of ineffectiveness. Shanafelt et al1 have contributed considerably to our understanding of this syndrome and have demonstrated that physician burnout can directly translate adversely to patient care, engagement, outcomes, and satisfaction. Most recent surveys suggest that more than 50% of surgeons suffer burnout. Of lately, but helpfully nonetheless, many healthcare leaders, hospital CEOs, and so on are now recognizing the scourge of burnout among physicians and the need to meaningfully address it, not only because it is the right thing to do, but because it is good business to do so. But this is an important discussion for another day.

With far less media attention, another physician—largely surgeon—epidemic is also unfolding. In increasing measure, surgeons of all stripes, but particularly from the fields of minimally invasive surgery (MIS), urology, and gynecologic oncology, are reporting musculoskeletal disorder (MSD) injuries and symptoms suffered as a result of simply going to work every day. It is hard to imagine that those responsible for any other workplace, let alone one where the stakes are so high for the customer, would tolerate rates of “worker injury” such as are now being reported by surgeons.

In this issue of Annals, Alleblas et al present a systematic review of the prevalence of MSD among surgeons performing MIS.

While thorough, their review focused (as advertised) only on surgeons performing MIS in the abdominal cavity, including general, gynecological, and urologic surgery. Reports on ergonomic risks factor violations among practitioners of flexible endoscopy, catheter-based interventional therapies, and open surgery, all of which manifest an evolving literature, were purposefully omitted.

There were still many interesting findings from the studies Alleblas et al reviewed. Apparently, despite our seeming habituation to the unhealthy reality, large populations of (nonmedical) workers studied in the United States and Europe report back pain and work-related MSD at a fraction of the rate suffered by surgeons.
Addendum

The authors found inconsistent response rates and rates of MSD reported across the studies reviewed. This is a fair criticism of the extant, particularly earlier literature. The authors report an average prevalence of MSD in 74% of surgeons included in their review. Accounting for the unlikely event that all (survey) nonresponders suffered no MSD, that overall average would dip to 22%. Yet, among the more recent publications cited in this review, there is a consistent reporting of injury and symptom rates, especially of back and neck MSD in excess of 70%.2–4

All reviewed studies were retrospective analyses, and as Alleblas et al note, subject to recall bias. There are more recent studies in which survey data were collected prospectively with similarly concerning results. We recently reported that open and MIS surgeons participating in a multicenter study scored their pain an average of almost 5 out of 10 at the start of their respective cases, on their operating room days!5

In searching for patterns of injuries, no consistent factors or surgeon demographics emerged in this review. It is no surprise that women surgeons continue to struggle and suffer with instruments designed for larger hand sizes.

So what can be done to address the ergonomic ravages exacted upon MIS surgeons as a result of simply going to work? The authors point to the need to seriously revisit the design of instruments and particularly their handles. The time of a “one size fits all” surgical instrument handle is well past. They must now be designed and tailored to surgeon glove/hand sizes. The authors also point out that the robotic platform has not proved the ergonomic boon that many thought it would be. MSD injury and symptom rates in excess of 50% attend the few robotic studies reported. Robotic surgery referenced in this review should more precisely be described as computer assisted surgery, as all employed a master-slave mechanism where a surgeon sat at a console and controlled distant end effectors. A truly robotic, automated system by contrast would theoretically hugely enhance the ergonomic experience of the operator. Such systems have seen very limited deployment to date across surgical specialties. Not surprisingly, current “Robotic surgeons” report symptoms similar to those who spend extended hours working with microscopes.

There will be a need of both high-tech (eg, re-visioning surgeon: patient and surgeon: device interfaces), and also low-tech (eg, employing intraoperative targeted stretching micro breaks)5 solutions to the problem of MSD among surgeons performing MIS.

Awareness and measurement of the problem is the first important step in taking the necessary strides to remedy it. The existing data, presented in this review, are spread wide and thin. Alleblas et al have helped to draw attention to this silent epidemic. They rightly call for a more concerted research effort to understand and thus begin to address the issues.
“Physician heal thyself” isn’t working

References

Bibliografie


Alleblas CCJ, Vleugels MPH, Nieboer TE. The effects of laparoscopic graspers with enhanced haptic feedback on applied forces: a randomized comparison with conventional graspers. *Surg Endosc.* 2017;31:5411-5417


Alleblas CCJ, Vleugels MPH, Stommel MWJ, Nieboer TE. Performance of a haptic feedback grasper in laparoscopic surgery: a randomized comparison with conventional graspers in a porcine model. *Submitted.*
Dankwoord
Dankwoord

Het is zover! Mijn proefschrift is af en daarbij past een woord van dank aan iedereen die in meer of mindere mate betrokken is geweest bij de totstandkoming van dit proefschrift.

Doctor Nieboer, beste Bertho. Allereerst wil ik jou bedanken voor de kans die je mij hebt geboden door mij een baan als onderzoeker te geven. Met jouw positieve blik weet jij als geen ander mensen te stimuleren het beste uit zichzelf naar boven te halen en daarnaast sturing te geven waar dat nodig is. De afgelopen jaren heb ik veel van je geleerd en was er naast de serieuze momenten gelukkig ook ruimte voor humor en persoonlijke interesse. Bedankt dat de deur altijd voor mij open stond en dat je altijd bereikbaar was, ook al was het soms 23:55 en moest nog even dat ene abstract de deur uit.

Doctor Vleugels, beste Michel. Ik heb veel bewondering voor jouw bevlogenheid (what’s in a name), veerkracht en doorzettingsvermogen. Wat hebben we binnen het EFRO FROI project een fantastisch onderzoekstraject opgezet en doorlopen. De onderzoeken bleven niet onopgemerkt in het buitenland en we hebben samen enkele vooraanstaande congressen bezocht op het gebied van minimaal invasieve chirurgie. Ik zal deze reizen en jouw verhalen nooit meer vergeten. Bedankt!!

Professor Vierhout, beste Mark. Veel dank voor uw vriendelijkheid, betrokkenheid en begeleiding van mijn promotietraject. Met uw klinische ervaring en betrokkenheid bij de opkomst van minimaal invasieve chirurgie in de gynaecologie zorgde u ervoor dat de ergonomische/technische secties leesbaar bleven voor de clinici. In het bijzonder bedank ik u voor uw rust om alles ten einde in goede banen te leiden.

Professor Jansen, beste Frank Willem. Onze samenwerking startte binnen het EFRO GUMS project. Ik heb veel bewondering voor uw kennis en vooruitstrevendheid. Op de congressen brachten we meestal even een bezoek aan de expositiehal van de industrie om kennis te nemen van de nieuwste technische ontwikkelingen die daar gepresenteerd werden. Onze overleggen waren altijd kort maar krachtig en vaak lag er, zonder dat dit per se de insteek was, meteen een heel nieuw onderzoeksplan op tafel. Ontzettend bedankt voor de inspirerende ontmoetingen.

Professor Stegeman, beste Dick. Voor mijn research internship bij bewegingswetenschappen klopte ik begin 2012 bij jou aan toen ik zag dat hiervoor een interessant ergonomisch vraagstuk beschikbaar was, aangedragen door Dr. Sietses. Ik wil jullie beide bedanken voor de aangename kennismaking met het wetenschappelijk onderzoek. Dick, ik heb jouw vriendelijkheid en voortdurende interesse in de voortgang van mijn promotie zeer gewaardeerd. Ik dank je voor het geven van het voorzetje bij Bertho om eens met elkaar in gesprek te gaan over de voortzetting van wetenschappelijk onderzoek.

Dit promotietraject was er niet geweest zonder twee bijzonder uitdagende projecten: het EFRO FROI en het EFRO GUMS project. Het eerste project komt uitgebreid aan bod in dit proefschrift, namelijk in hoofdstuk 5, 6, en 7. Graag wil ik hier van de gelegenheid gebruik maken om alle leden van de GUMS projectgroep te bedanken voor de prettige samenwerking. In het bijzonder een woord van dank aan medepromovendus binnen dit project Lukas van den Haak; voor de samenwerking aan twee systematische literatuur-studies en experimenteel validatie onderzoek. Hoewel er geen specifiek hoofdstuk aangaande GUMS in dit proefschrift is opgenomen, hebben de ervaringen in dit clinically driven project, wel degelijk een bijdrage geleverd aan het afsluitende hoofdstuk van dit proefschrift.

Doctor In ’t Hout, beste Joanna, fijn dat jij voor me klaar stond om te ondersteunen bij de statistische berekeningen. Onze overleggen waren, mede dankzij jouw oprechte interesse, altijd zeer constructief en door jouw heldere uitleg leerde ik steeds weer iets nieuws. In het bijzonder bedankt voor jouw bijdrage aan hoofdstuk 3 waarin jouw expertise aangaande de HKSJ methode heel erg belangrijk was.

Graag bedank ik alle coauteurs die een bijdrage hebben geleverd aan een hoofdstuk in dit proefschrift. Beste Anne Marie de Man, het was een lange rit maar uiteindelijk hebben we ons een weg gebaand door alle 7844 zoekresultaten. Bedankt voor jouw bijdrage aan hoofdstuk 3. Dr. Coppus en Dr. Stommel, beste Sjors en Martijn, dank voor jullie input bij respectievelijk hoofdstuk 6 en 7.

Ook bedank ik alle personen die hebben deelgenomen aan mijn onderzoeken. Soms was de deelname relatief ontspannen, namelijk door het invullen van vragenlijsten (hoofdstuk 2 en 5) en soms werd er wat meer inspanning gevraagd. Daarom in het bijzonder dank aan diegene die mee hebben gedaan aan het EMG onderzoek (hoofdstuk 4) en aan het experimenteel onderzoek (hoofdstuk 6 en 7).
Dankwoord

Beste (ex-)collega’s uit de onderzoekstuin. Vaak zagen jullie mij binnenlopen met een nieuwe gadget of enorme laparoscopische oefenbox met het liefst nog een boodschappentas vol toebehoren ernaast en soms met een nieuwe plant om de kantoor tuin wat op te fleuren; een gedeelde hobby onder ons kantoortuinbewoners. Ik wil jullie bedanken voor de fantastische onderzoekersweekenden en het skiweekend naar Sölden. Bovenal wil ik jullie bedanken voor de goede sfeer, wederzijdse interesse in elkaars onderzoek en natuurlijk het delen van successen middels de publicatietaarten.

Lieve collega’s van het Trial Office (VUmc), ik wil jullie in het bijzonder bedanken, niet alleen voor jullie belangstelling maar zeker ook voor jullie flexibiliteit en begrip als ik weer eens op korte termijn vrij moest vragen voor mijn onderzoek.

Lieve vrienden en familie, ontzettend bedankt voor jullie belangstelling in mijn werk en het sociale leven hieromheen, jullie zijn heel belangrijk voor mij. Vriendinnen van de Andreashof en van Quintus, wat geniet ik van onze stapavondjes en weekendjes weg. Laten we dit vooral nog heel veel jaar voortzetten!

Lieve pap en mam, ontzettend bedankt voor jullie onvoorwaardelijke steun; jullie staan altijd voor mij klaar. Het mooie is dat jullie ook zeker jullie steentje hebben bijgedragen aan mijn promotieonderzoek. Pa, wat was het leuk dat wij samen konden werken aan de constructie van een nieuwe laparoscopische oefenbox en experimentele opstelling, daar komt jouw vaardigheid als lasser toch altijd wel weer goed van pas. Ma, bedankt dat je er altijd voor mij was als ik weer eens een luisterend oor nodig had tijdens het hardop nadenken en schrijven van een nieuwe introductie of discussie. Het leuke is dat een gedeelte van dit proefschrift zelfs nog aan mijn bureautje bij jullie thuis geschreven is en vervolgens een gedeelte in mijn nieuwe huis, Maasdijk. Niet al te ver van Kwintsheul dus en dat zorgt ervoor dat we nog zeer regelmatig samen gezellig een bakkie kunnen doen. Pap en mam, ik houd van jullie en ben trots dat jullie mijn ouders zijn.

Lieve Denise, ik ben je dankbaar voor alles wat je voor mij doet. Bij jou kan ik thuiskomen. Met enige regelmaat moest jij je vrienden en familie vertellen dat “Chan nog bezig was met haar onderzoek”. Het combineren van een promotietraject in Nijmegen naast een baan als datamanager in Amsterdam zorgde voor een enorm drukke periode met weinig tijd voor elkaar. Het is nu dan ook de hoogste tijd om daar verandering in te brengen. Ik hoop met jou nog veel van de wereld te mogen zien en vooral te genieten van het goede leven in Maasdijk. Ik hou van jou!