# Training, efficiency and ergonomics in minimally invasive surgery

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# Training, Efficiency and Ergonomics in Minimally Invasive Surgery

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# Contents

# Chapter 1

# General introduction and outline of the thesis

## Introduction and outline of the thesis

Modern laparoscopic surgery commenced in the late nineteen eighties with the first laparoscopic cholecystectomies that were performed in Germany and France [1,2]. In the next twenty-five years, Minimally Invasive Surgery (MIS) has been rapidly expanding as the treatment of choice for an ever-growing number of indications in abdominal surgery. The reason for this shift towards MIS has multiple causes.

The first one to be mentioned is reduced morbidity. Less blood loss, less postoperative pain, shorter hospital admissions, quicker reintroduction into society, and a superior cosmetic result are some well-established advantages when using these minimally invasive techniques in advanced and complex procedures such as colorectal surgery [3].

Furthermore, because of this reduced morbidity, with the introduction of MIS and emerging technical possibilities, more and more specific procedures can be offered to a greater public. Anti-reflux surgery and bariatric surgery, for instance, were complicated procedures with considerable morbidity and mortality when using open techniques. MIS significantly reduced morbidity and mortality, making these procedures an attractive alternative for life-long conservative therapy. Also, the popularity of living-related kidney donation programs grew significantly since the living donor could be offered a minimally invasive technique with reduced morbidity to remove the donated kidney [4].

A third and important reason for the shift towards MIS techniques is the wish of the patient. Although there is no proven benefit for all MIS procedures, patients, often well-informed after consulting the internet, ask for a laparoscopic approach for an appendectomy instead of the traditional McBurney's incision, the latter being just as good in all published data so far. A critical and open mind is mandatory when counseling these cases.

Finally, applying and promoting new techniques in an institute and clinical research group can generate positive attention and can possibly cause a commercial benefit for the hospital, the regional insurance company and the surrounding community. Here again, a critical approach is advised to protect the safety and well-being of the patient on one hand without denying the benefits of new techniques on the other.

Besides all these established and potential benefits, the introduction of MIS also brought a number of challenges into the surgical practice, especially for the operating team and for the training of residents. Ergonomic challenges are expressed in the way the operating team has to prepare, operate and interact with a wide variety of additional laparoscopic equipment e.g. electrocautery, insufflation, visualization and illumination of the operating field [5].

Efficiency of the operative process is challenged due to the additional equipment that has to be prepared, installed and sometimes repaired in case of malfunctioning without compromising patient safety.
Teaching minimally invasive surgery to surgical residents and others in this era also confronts the surgeons with new challenges and opportunities. Since MIS involves the use of additional equipment and visualization of the operating field via a monitor, the training of basic motor skills can be performed outside the operating room (OR) on box trainers and virtual reality simulators.[6] When the basic skills are mastered, the procedural training inside the OR can be optimized with the help of the equipment that is present inside the modern MIS suite.

In this thesis, important factors that influence OR ergonomics and efficiency are addressed and a structured curriculum for MIS training inside the OR is introduced.

In **Part I** (chapter 2,3, and 4) ergonomic challenges and efficiency aspects of MIS are discussed. The interaction with, and positioning of the equipment necessary for MIS and the operating team is very important for the ergonomic quality and efficiency of a procedure and can be influenced and improved substantially.

**Chapter 2** gives a general overview of ergonomic aspects for MIS, especially in relation to optimal monitor positioning for the OR team and OR setup.
**Chapter 3** focuses on the ergonomic situation of the cervical spine during laparoscopic cholecystectomy. We performed a posture analysis during this common laparoscopic procedure and compared the situation in a conventional OR that is prepared for a laparoscopic procedure with the situation in a dedicated MIS suite. This is a high-tech OR that is specifically designed for the additional requirements that are needed for performing MIS procedures.
**Chapter 4** describes an experimental study that was performed to objectively assess the potential benefit in OR-efficiency during the interoperative period for the dedicated MIS suite. We performed efficiency measurements with dedicated MIS nurses who were asked to prepare the OR for both a standard and a complex MIS procedure. Secondly we asked them to clean up the OR for the next procedure. Measurements were compared for the situation in a conventional OR that is prepared for a laparoscopic procedure with the situation in a dedicated MIS suite.

In **Part II** (chapter 5 and 6) of this thesis, we focused on the new opportunities in procedural training for residents that are prepared to perform MIS. Until the introduction of MIS, almost all open procedures were entirely learned using the Master-Apprentice-Model. The apprentice (resident) prepared for a procedure by studying the theory and he might have followed a basic pre-clinical course before he went to the OR with the master (surgeon). In the OR, the master initially shows the apprentice how a specific procedure is done, and, after assisting the surgeon during a certain number of procedures, the apprentice is gradually allowed to perform parts of the procedure while the master supervises the apprentice.

With MIS, on the other hand, the operating field is indirectly displayed on a monitor that is placed away from the patient. This created opportunities to train several skills outside the OR. Basis laparoscopic motor skills can be repetitively trained and assessed on virtual reality (VR) simulators. Small steps of a procedure and specific skills necessary for a procedure can be trained using a box trainer that provides the same haptic feedback as in the actual surgery. When opportunities arise, even entire procedures can be performed on human cadavers or on animal models. Only after these basic skills and the elementary procedural skills are safely mastered in a skills lab, the trainee enters the OR and starts performing procedures on real patients.

**Chapter 5** describes the learning effect of a new training method for the transition from the skills lab to the OR using intra-operative instruction video's. We hypothesized that implementation of this training method called INtra-operative Video-Enhanced Surgical procedure Training (INVEST) can enhance the early learning effect when compared to the Master-Apprentice-Model alone for residents that start with procedural training inside the OR.

**Chapter 6** concerns the same cohort of trainees using INVEST. This chapter further focuses on the other important aspects of procedural training inside the OR in daily practice: Effectiveness of the method, efficiency of the method and its impact on OR-efficiency in general.

Finally, **Chapter 7** provides a general discussion on the content of this thesis and future perspectives of developments and research projects are provided.

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# Chapter 2

# Optimal ergonomics for laparoscopic surgery in minimally invasive surgery suites: a review and guidelines

**M.J. van Det, W.J.H.J. Meijerink, C. Hoff, E.R. Totte, J.P.E.N. Pierie**

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## Abstract

*Background* With minimally invasive surgery (MIS), a man–machine environment was brought into the operating room, which created mental and physical challenges for the operating team. The science of ergonomics analyzes these challenges and formulates guidelines for creating a work environment that is safe and comfortable for its operators while effectiveness and efficiency of the process are maintained. This review aimed to formulate the ergonomic challenges related to monitor positioning in MIS. Background and guidelines are formulated for optimal ergonomic monitor positioning within the possibilities of the modern MIS suite, using multiple monitors suspended from the ceiling.

*Methods* All evidence-based experimental ergonomic studies conducted in the fields of laparoscopic surgery and applied ergonomics for other professions working with a display were identified by PubMed searches and selected for quality and applicability. Data from ergonomic studies were evaluated in terms of effectiveness and efficiency as well as comfort and safety aspects. Recommendations for individual monitor positioning are formulated to create a personal balance between these two ergonomic aspects.

*Results* Misalignment in the eye–hand–target axis because of limited freedom in monitor positioning is recognized as an important ergonomic drawback during MIS. Realignment of the eye–hand–target axis improves personal values of comfort and safety as well as procedural values of effectiveness and efficiency.

*Conclusions* Monitor position is an important ergonomic factor during MIS. In the horizontal plane, the monitor should be straight in front of each person and aligned with the forearm–instrument motor axis to avoid axial rotation of the spine. In the sagittal plane, the monitor should be positioned lower than eye level to avoid neck extension.

## Introduction

Ergonomics, defined as ''the science that deals with the consideration of human characteristics, expectations, and behaviors in the design of things people use in their work and everyday lives and of the environments in which they work and live'' was introduced into the surgical specialties together with the implementation of MIS [1, 2].
In contrast to open surgery, in which the surgeon works directly on the patient with the use of traditional instruments, in MIS, the surgeon interacts with several technological applications to perform the surgical procedure. The goal of ergonomics is to design a man–machine environment that enhances effectiveness and efficiency in their interaction while desirable human values such as safety and comfort are maintained or even enhanced [2]. In MIS, as in most fields wherein ergonomics is applied, there is no perfect ergonomic solution for the man–machine environment. Therefore, an acceptable balance must be created between effectiveness and efficiency on the one hand and operator safety and comfort on the other. This balance is not fixed but dependent on the performance and versatility of the available equipment and on the compliance and physical and mental abilities of its operators.

## Methods

The ergonomic drawbacks of MIS and the concept of ceiling-suspended monitors, as present in the dedicated minimally invasive surgery suite (MIS suite), with potential ergonomic improvements are addressed. We reviewed the available literature on the effectiveness and efficiency aspects as well as the comfort and safety aspects of ergonomic monitor positioning for MIS. Literature searches in PubMed on the effectiveness and efficiency of MIS in relation to monitor positioning were conducted. ''Efficiency'', ''laparoscopy'', and ''posture'' were identified as relevant Medical Subject Heading (MeSH) terms and were used in several combinations and with other non-MeSH terms (''effectiveness'', ''monitor'', ''display'', ''position'' and ''ergonomics'') to identify the available literature. Literature searches in PubMed on the comfort and safety aspects of monitor positioning in surgical and nonsurgical professions were conducted. ''Human engineering'', ''posture'', ''safety'', and ''data display'' were identified as relevant MeSH terms and were used in several combinations and with other non-MeSH terms (''position'', ''height'' and ''musculoskeletal'') to identify the available literature.
The search results were evaluated in terms of applicability and articles with a poor scientific setup were excluded. As a conclusion, we transformed the results of the reviewed literature into guidelines for creating a safe but efficient balance of ergonomic monitor positioning in the operating room (OR).

# Results

## Ergonomic problems in MIS

Compared with open surgery, a number of MIS ergonomic factors differ before, during, and after the procedure. Unique laparoscopic equipment such as monitors, insufflators, light sources, video equipment, and electrocautery devices are set up on one or multiple trolleys. These trolleys must be installed, operated, and put away by the OR team. They usually are not stored inside the OR itself but elsewhere in the OR complex. Heavy and time consuming to install, the trolleys pose a possible threat to the safety of patients and personnel in the OR because they take up a lot of space and clutter the floor with cables and tubing [3–5]. The instruments that the surgeons and assisting surgeons use for MIS have long shafts, which can be inserted into the abdominal cavity only through fixed ports, called trocars, that serve as rotation points. As a result, the instrument's motion is inverted inside the abdomen with a varying scaling effect. This phenomenon is known as the fulcrum effect [6]. The range of motion for the laparoscopic instruments is limited to five degrees of freedom, allowing less dexterity than the natural range of motion in open surgery [7]. Feedback from the instruments and the surgeon's actions also has changed. The long, rigid instruments magnify the surgeon's natural hand tremors and diminish tactile feedback. During laparoscopic surgery performed in a traditional OR, the operative field is visualized indirectly with a laparoscope connected to a camera that projects a two-dimensional image on a monitor. The monitor is positioned outside the sterile operating field at a certain height and distance, which forces the surgeon to work in one direction while viewing in another. Due to the monitor's fixed position on top of the trolley, the adjustment possibilities of the monitor are very limited, in both height and ideal position [8]. The deviation between the forearm–instrument motor axis and the visual axis that provides feedback for the surgeon's actions can be extensive during MIS. This discrepancy depends on multiple factors such as positioning of the patient and the OR team inside the OR, the type of procedure, and the number of available monitors and ways they can be positioned. In addition, members of the team frequently must adopt uncomfortable neck positions in the axial (rotation) and frontal (extension) planes to be able to see the intra-abdominal image. This causes eyestrain and physical discomfort of the neck, shoulders, and upper extremities [5, 9–11]. Compared with open surgery, the posture during MIS is very static, which can exacerbate musculoskeletal problems, especially when the posture is uncomfortable [12, 13]. These changes in operative technique, equipment, instrumentation, and visualization have created a work environment that is ergonomically challenging for the OR team, possibly posing a threat for the safety of patient and employees.

## Ceiling-suspended monitors

To overcome some of the ergonomic challenges of visualization in this man–machine environment, ceiling suspended monitors were first introduced as a part of the MIS suite concept in the 1990s. Modern MIS suites are equipped with permanently installed laparoscopic equipment that is operational on demand inside the OR. The equipment, together with multiple flat-screen monitors, is attached to a ceiling-mounted suspension system to facilitate versatile positioning around the operative field [14,15]. Each monitor can be adjusted in location, height, and inclination. This increases freedom in monitor positioning and makes it possible to bring the visual axis back to the motor axis, which can facilitate good vision and a comfortable posture for all members of the operating team [16].

## Optimal monitor position, effectiveness, and efficiency

Five evidence-based, experimental studies were identified (Table 1). Erfanian et al. proved that in-line projection of the laparoscopic image is an independent factor reducing procedure time for laparoscopic appendectomy [17]. With an inline projection system close to the operators' working area, procedure time could be reduced by an average of 6 min. The other four studies were experimental investigations with measurements performed in a controlled environment. The very similar results from all five studies suggest that task performance in terms of both speed and accuracy can be influenced by monitor position [18–21]. The screen is preferably positioned straight ahead of the surgeon in line with his forearm–instrument motor axis. In addition, the screen should be positioned far below eye level and near the operative field, allowing ''gaze-down'' viewing. These measures bring the visual axis back to the motor axis, which improves the surgeon's performance in terms of both speed and accuracy.

To improve viewing direction and to overcome the difficulties of two-dimensional (2D) feedback diverted away from the three-dimensional (3D) work field, a number of new imaging devices have been developed and tested with varying results [16, 22–26]. Many of these devices (3D screens, 3D goggles, robots, projection devices) are expensive, inconvenient, or very complicated, or have a poor resolution compared with the 2D cathode ray tube (CRT) monitor, which makes them unsuitable for everyday practice. To date, the only affordable and practical solution for inclined and individually adjustable imaging seems to be by use of multiple flat screen monitors attached to a suspension system, as present in MIS suites. In the modern MIS suite, high-definition flat screen monitors can be positioned apart from the rest of the equipment. The suspension system even allows placement above the patient, intraoperative repositioning, and inclination of the screen. The high-definition 2D image is of superior quality compared with that of a CRT monitor. We have already demonstrated in another study that it is possible to enhance gaze-down viewing significantly for the operator and improve neck ergonomics for other members of the OR team [27].

**Table 1.** Overview of ergonomic research on monitor positioning: Effectiveness and efficiency aspects

| Author | N | Design | Methods | Results |
|---|---|---|---|---|
| Erfanian [17] | 108 | Randomized controlled trial. | Measurement of time to perform a laparoscopic appendectomy with a regular laparoscopic tower or in-line projection. | Operating time was significantly shorter for the in-line projection (6 minutes, $P$=0.013) |
| Hanna [18] | 10 | Randomized controlled trial. | Measurement of time and quality of intracorporeal knot-tying in different monitor positions. | Both knot quality ($P$<0.01) and execution times ($P$<0.01) were improved with the monitor straight in front of the operator at the level of the hands |
| Haveran [19] | 24 | Randomized controlled trial. | Measurement of time to perform a one-handed task during 3 different monitor positions (left, front, right) at eye height. | Task time is significantly shorter with the monitor straight in front of the performer. ($P$=0.048) |
| Matern [20] | 18 | Randomized controlled trial | Measurement of task performance and muscle activity of a 2 handed task with a monitor frontal and sideways at eye level, and frontal at operating field level. | Task performance was best with the monitor positioned frontal at operating field level. Muscle activity was minimal with the monitor frontal at eye level. |
| Omar [21] | 20 | Randomized controlled trial | Measurement of time and errors for one-handed and two-handed tasks with the display at eye- and hand-level | For one- and two handed tasks, time ($P$<0.001) and errors score ($P$<0.001) was significantly better with the display at hand-level |

## Optimal monitor position, comfort, and safety

Working with a monitor or another form of visual display unit (VDU) can cause discomfort and fatigue, especially for the visual and musculoskeletal systems [13, 28]. In the 1980s, when occupational use of VDUs was becoming increasingly common, eyestrain, influencing work performance in a negative way, was reported for up to 85% of VDU users [29]. Prolonged visual activity during work close up causes the eyes to converge and the lenses to accommodate, resulting in continuous and prolonged contraction of the extraocular and ciliary muscles, which can lead to eyestrain [28, 30]. Research in this field suggests that eyestrain is influenced by at least two components involving monitor position: the viewing distance between the monitor and the observer and the monitor height in relation to the observer's eye height. Experimental studies performed by Jaschinski-Kruza [28], Jaschinski et al. [31], and Menozzi et al. [32] focused on eyestrain during work with a monitor. They provide evidence that eyestrain is evoked by elevated and near monitor positions. These studies also demonstrate that minimal eyestrain is evoked when these two components are adjusted to minimize extraocular and ciliary muscle activity. The neutral orientation of the human eye in its orbit is at an inclined angle of approximately 15°. In a relaxed state, the accommodation of the unrefracted human eye is an average of 1.3 diopters (0.8 m), and the average conversion distance is 1 m [28]. In this position, the orbital and ciliary musculature is in its most relaxed state. Musculoskeletal discomfort and fatigue of the lower back, neck, and shoulders also are frequently reported among VDU workers [29, 33]. Most of these complaints are believed to be caused by prolonged static postures that require continuous static muscle contraction of the back, neck, and shoulders musculature. Continuous isometric muscle contraction reduces the muscle's perfusion, resulting in decreased nutrient flow and removal of waste products, which can lead to muscle fatigue and pain [34]. A poor ergonomic posture is believed to accelerate this process because muscles must perform isometric contractions outside their neutral length range. Outside the neutral range, muscles require more energy to generate the same contractile force. In addition, more contractile force of both agonist and antagonist muscles is needed because joints usually are unstable outside their neutral position.

The relation between monitor position and musculoskeletal discomfort and fatigue has been investigated to objectify posture-related complaints and to design an ergonomic VDU work environment that minimizes the risk of these musculoskeletal and visual complaints [16, 31, 32, 35]. Bauer and Wittig [36], Seghers et al. [37], and Turville et al. [38] performed electromyographic studies investigating neck musculature responses to monitor heights in relation to the eyes of the viewer [36–38]. All these authors registered the lowest cervical muscle activity for monitor positions at or just below eye height. Muscle activity increased with lower monitor positions, but did not necessarily lead to muscle fatigue. In addition, Seghers et al. [37] found a significant increase in muscle activity during 90-min exercises with monitor positions above eye level, suggesting that elevated monitor positions may cause early muscle fatigue. Neck extension increases with higher monitor positioning, while lower monitor positions lead to neck flexion [36, 39]. These results also were consistent with the personal preference of the subjects. Table 2, presents the results of the individual studies.

**Table 2.** Overview of ergonomic research on monitor positioning: Comfort and Safety aspects

| Author | N | Design | Methods | Results |
|---|---|---|---|---|
| Bauer [36] | 8 | Randomized controlled trial | Effect of monitor position on cervical muscle activity (display at 0°, -17,5°, -35°) | Muscle effort increased with angle. Subjective strain was not influenced. Preferred position between 0° and -17,5° |
| Jaschinski-Kruza [31] | 22 | Clinical trial | Eyestrain assessment for high and low and far and near monitor positioning | High positions up close resulted in more eyestrain than low screens. Gaze direction of -8° was preferred for eyestrain. |
| Jaschinski-Kruza [28] | 20 | Clinical trial | Tracking task at on a display at 50 cm, 100 cm and at preferred distance | 50 cm was judged as too near. 100 cm was accepted. Mean preferred distance was 74 cm. |
| Menozzi [32] | 114 | Clinical trial | Assessment of most comfortable direction of gaze | Preferred mean direction of gaze was -12,3° |
| Seghers [37] | 16 | Randomized controlled trial | Analysis of EMG, video images and subjective scores of a computer task at 4 different screen heights | EMG data suggests that prolonged work at a high monitor position might be harmful. |
| Turville [38] | 12 | Randomized controlled trial | Effects of viewing angle (-15°, -40°) on muscle activity and performance during computer task performance | Muscle activity was higher at the -40° viewing angle ($P$<0.01). There were no differences in muscle fatigue of performance. |

# Discussion and conclusions

Monitor position in laparoscopic surgery is an important determinant of the ergonomic situation during a procedure. The introduction of ceiling-suspended monitors, as present in the MIS suite concept, allows versatile monitor positioning apart from the rest of the laparoscopic equipment.

In this review, we summarize the available literature on ergonomics and monitor positioning, separating the effectiveness and efficiency aspects from the comfort and safety aspects of the work environment. Ergonomics studies provide evidence that laparoscopy is a more static type of surgery than open surgery. These studies therefore advise that postures during surgery should be as neutral as possible when prolonged static posture is inevitable.

Functional laparoscopic studies point out that laparoscopic tasks are performed significantly quicker and more precisely when the monitor is placed in the proximity of the surgeon's hands, in line with the surgeon's forearm–instrument motor axis. Studies on eyestrain recommend avoidance of elevated monitor positions above eye level. A downward viewing direction of 15° is the most neutral viewing direction for the extraocular musculature. The distance to the monitor should be 80 to 120 cm for avoidance of excessive accommodation, convergence, and staring. This distance is based on a regular 19-in. laparoscopic CRT monitor and is of course dependent on the screen size and image resolution. With 21-in. high-definition monitors, a viewing distance of 80 cm may be considered too close.

Combining these data, we can conclude that for optimal effectiveness and efficiency during laparoscopic interventions, the monitor should be placed in direct proximity to the operating field to prevent axial rotation of the neck and to allow downward viewing for realignment of the visual axis with the working axis.

For optimal comfort and safety during laparoscopic procedures, the monitor should be placed at or just below eye level to minimize musculoskeletal fatigue of the neck and shoulders, and at a moderately inclined viewing angle to reduce eyestrain with near work. The viewing distance is preferably between 80 and 120 cm.

The most suitable monitor position is a balance between the ergonomic aspects of effectiveness and efficiency on the one hand and comfort and safety on the other. This balance varies per individual, per discipline, and per procedure. For individual fine-tuning, however, it is important that every person who performs laparoscopic tasks be aware of this balance. This awareness will enable each person to create his or her own man–machine environment using the possibilities of suspended-monitor positioning.

The different disciplines working at the operating table perform different tasks. This also can lead to different preferences in monitor positioning. For the operating surgeon, the effectiveness and efficiency side of the balance is very important, favoring a low monitor position near the operating field to allow an inclined viewing direction in line with the working axis. For the assisting surgeons and scrub nurses, who usually are not extensively involved in the operative procedure itself but perform assisting tasks, the safety and comfort side of the balance outweighs the effectiveness and efficiency side.

The type of procedure also can influence the balance. Prevention of musculoskeletal complaints is a larger issue during long and complex procedures, in which the comfort and safety aspect is emphasized more than during short procedures.

# Guidelines

## Monitor positioning

- In the horizontal plane, the monitor should be straight in front of each person in line with the forearm–instrument motor axis, avoiding axial rotation of the spine (Figure 1A).
- In the sagittal plane, the monitor should be positioned lower than eye level to avoid neck extension (Figure 1B). The most comfortable viewing direction is approximately 15° downward. The most efficient monitor position is near the operative field, implicating a more inclined viewing direction.

- Viewing distance is highly dependent on monitor size. It should be far enough to avoid extensive accommodation of the eyes and conversion by the extraocular musculature, and it should be close enough to avoid staring and loss of detail.

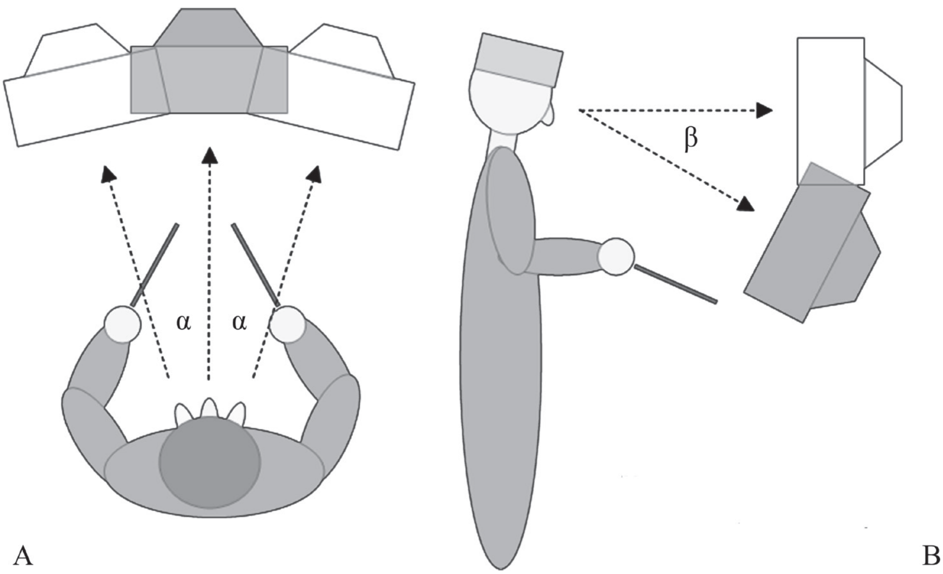


**Figure 1. A:** Monitor position in the horizontal plane with angle α< 15º between viewing direction and working direction. **B:** Monitor position in the sagittal plane with viewing direction β for the surgeon (-10° < β < -30°) and the assisting OR team (0° < β < -15°)

## Patient positioning

- The patient's position should be chosen to ensure that abducted arms for the anesthetic team do not prevent low monitor positioning.
- The patient should be positioned such that the operator can work directly in front of him or her. For many procedures in the upper abdomen, the operator stands between the legs of the patient.

## Positioning of the laparoscopic equipment

- The equipment as well as the cables and tubes running from the equipment to the patient should not disrupt the eye–hand–target axis of the operating surgeon.
- It is important to ensure that the equipment does not block the view of the assisting surgeons and nurses.

## Positioning of the assisting surgeons and nurses

- The position of the assisting surgeons and nurses should not disrupt the eye–hand–target axis of the operating surgeon.
- The person operating the laparoscope must be positioned to do so in a neutral position with a clear, straight view on a monitor.

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# Chapter 3

# Ergonomic assessment of neck posture in the minimally invasive surgery suite during laparoscopic cholecystectomy

**M.J. van Det, W.J.H.J. Meijerink, C. Hoff, M.A. van Veelen, J.P.E.N. Pierie**

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## Abstract

*Background* With the expanding implementation of minimally invasive surgery, the surgical team is confronted with challenges in the field of ergonomics. Visual feedback is derived from a monitor placed outside the operating field. This crossover trial was conducted to evaluate and compare neck posture in relation to monitor position in a dedicated minimally invasive surgery (MIS) suite and a conventional operating room.

*Methods* Assessment of the neck was conducted for 16 surgeons, assisting surgeons, and scrub nurses performing a laparoscopic cholecystectomy in both types of operating room. Flexion and rotation of the cervical spine were measured intraoperatively using a video analysis system. A two-question visual analog scale (VAS) questionnaire was used to evaluate posture in relation to the monitor position.

*Results* Neck rotation was significantly reduced in the MIS suite for the surgeon ($p = 0.018$) and the assisting surgeon ($p<0.001$). Neck flexion was significantly improved in the MIS suite for the surgeon ($p<0.001$) and the scrub nurse ($p = 0.018$). On the questionnaire, the surgical team scored their posture significantly higher in the MIS suite and also indicated fewer musculoskeletal complaints.

*Conclusions* The ergonomic quality of the neck posture is significantly improved in the MIS suite for the entire surgical team.

# Introduction

Minimally invasive surgery (MIS) plays a major part in modern abdominal surgery, urology, and gynecology and has become the treatment of choice for a still growing number of procedures. Most of the advantages with MIS are patient related. Less blood loss, less postoperative pain, shorter hospital admissions, quicker reintroduction into society, and a superior cosmetic result are some well-established MIS advantages [1–4].

On the other hand, MIS confronts the surgeon and his or her team with some challenging aspects, primarily in the area of ergonomics and efficiency [5, 6]. The necessity of additional equipment—including electrocautery and insufflation devices, monitors, video equipment, wiring, and tubing, usually stored outside the operating room on large heavy trolleys—has compromised operating room efficiency and prolonged turnover times [7].

During the procedure, the surgeon must work with long instruments that move invertedly inside the abdomen and with a certain scaling effect, also known as the fulcrum effect [8]. The entire operating team derives the visual feedback of their actions from a monitor positioned on top of a laparoscopic trolley that stands outside the operative field and away from the patient. Due to this positioning, the line of vision is diverted away from the line of action, creating an awkward posture including rotation of the spine, extension of the neck, and elevation of the upper extremities. This causes musculoskeletal complaints and possibly compromises surgical task performance [9–12].

Many different solutions have been devised to overcome these various drawbacks of MIS. The most versatile and most achievable solution is the dedicated minimally invasive surgery (MIS) suite [7, 13, 14]. These fully integrated operating rooms are equipped with permanently installed laparoscopic equipment that is operational on demand inside the operating room. This equipment, together with multiple flat-screen monitors, is attached to a ceiling mounted suspension system to facilitate versatile positioning around the operative field. The increased freedom of monitor positioning should, when used correctly, provide an improved ergonomic posture for the entire operating team and prevent extreme head and neck angulations in the axial and sagittal plane.

This study compared the ergonomic posture of the cervical spine for the entire operating room team during laparoscopic cholecystectomy performed in the traditional operating room with a cathode ray tube (CRT) monitor on top of a laparoscopic trolley and in the MIS suite with flat screen monitors suspended from the ceiling. We hypothesized that there would be a significant improvement in neck posture for the entire team in the MIS suite, resulting in a better ergonomic work environment and a reduction in posture-related musculoskeletal complaints.

# Methods

## Study design

The study was performed in the Department of Surgery at the Leeuwarden Medical Center (MCL). In a clinical setting, we analyzed the posture of the cervical spine of the surgeon, the assisting surgeon, and the scrub nurse during laparoscopic cholecystectomies for patients with symptomatic cholecystolithiasis. For this study, 16 surgeons, 16 assisting surgeons, and 16 scrub nurses were randomly assigned to perform their tasks during a laparoscopic cholecystectomy in a traditional operating room or MIS suite.
After assessment of the first operation, those assigned to the MIS suite performed their second cholecystectomy in a traditional operating room and vice versa, allowing each participant to be his own matched control. Flexion and rotation of the cervical spine was monitored with a video analysis system for 5 min during the dissection of Calot's triangle. During this stage of the cholecystectomy, the tasks of the operating room team and their position around the table is submitted to little variance between different cases, and the entire team is focusing on the monitors. Therefore, the surgical team's neck posture is completely dependent on the monitor position in relation to the operating table.

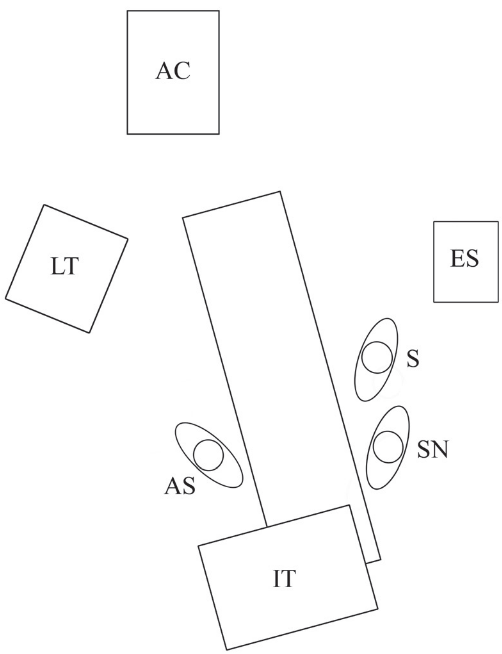


**Figure 1.** Operative set-up in the conventional OR. **AC.** Anesthesia console. **LT.** Laparoscopy trolley. **ES.** Electrocautery and suction devices. **S.** surgeon. **AS.** Assisting surgeon. **SN.** Scrub nurse. **IT.** Instrument table.

In the traditional operating room, the laparoscopic equipment is installed on a movable trolley. On the top of this trolley, one CRT monitor is installed on a rotating platform. This 19-in. monitor is not height adjustable, and the center of the screen is elevated 165 cm from the floor. For a laparoscopic cholecystectomy, we use a single trolley with one CRT monitor positioned at the right top end of the table, opposite the surgeon, who stands on the left side of the table (Figure 1). On the left side of the surgeon stands the scrub nurse. She prepares the instruments and operates the camera. An assisting surgeon stands on the right side of the table. He controls a grasping forceps that provides traction on the gallbladder for visualization of the operative field.

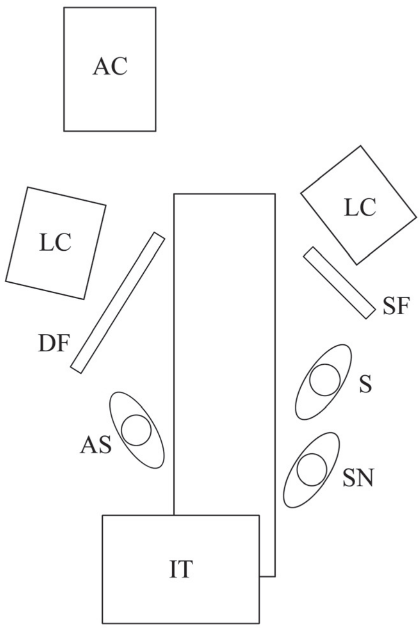


**Figure 2.** Operative set-up in the MIS suite. **AC.** Anesthesia console. **LC.** Laparoscopic consoles on pneumatic booms. **DF.** Double flatscreen. **SF.** Single flatscreen. **S.** surgeon. **AS.** Assisting surgeon. **SN.** Scrub nurse. **IT.** Instrument table.

In the MIS suite, the surgical team has similar positions around the table, and all three available monitors are used (Figure 2). A dual flat panel is positioned on the right side of the table opposite the operator and the scrub nurse. A third flat screen is positioned on the left side of the table for the assisting surgeon. Screen height, distance, and inclination can be adjusted to the preference of the observers.

For the surgeon, the screen is ideally placed right in front near his hands and instruments to permit a moderate downward viewing angle of 10° to 30° without axial rotation [10, 15, 16]. For the assisting surgeon and the scrub nurse, the screen is ideally placed just below eye level to allow a slightly downward viewing direction of 0° to 15°. Upward viewing angles that cause harmful neck extension are to be avoided. For all the participants, minimal neck torsion was aspired. An axial rotation less than 15° was considered ergonomically acceptable.
Body posture assessment was performed with a video analysis system consisting of two digital cameras mounted on a standard and connected to a laptop computer. One camera was positioned above the participant for observation of the axial rotation of the head compared with the trunk. The second camera was positioned perpendicular to the participant's viewing direction for observation of the head's flexion in the sagittal plane. The cameras took pictures simultaneously every 2 s for a period of 5 min per participant (150 photos per camera per participant).
After each procedure, every participant was asked to fill in a questionnaire containing two questions that had to be answered on a 100-mm visual analog scale (VAS). The first question asked the participant to judge the ergonomic quality of his or her posture in relation to the monitor position on a scale of 0 (very bad) to 100 (optimal). The second question asked the participant to indicate whether any musculoskeletal complaints were experienced as a result of his or her posture on a scale of 0 (no complaints) to 100 (disabling complaints).

## Data analysis

Measurements on the photos were digitally performed with a line-angle measuring tool in Adobe Photoshop 9.0 (Adobe Systems Incorporated, San Jose, CA, USA). To facilitate accurate measurement in the horizontal plane (rotation), we attached markers on the surgical hat and on the acromion of each shoulder. For measurements in the sagittal plane, we used the anatomic ear–eye line (EEL) running through the tragus of the ear and the canthus of the eye (Figure 3A). In neutral position of the head and neck, the EEL has an inclined angle of approximately 15° to the horizontal [16].
We also recorded eye height and screen height in relation to the floor and the viewing distance from eye to monitor to enable calculation of the viewing direction (viewing direction = Sin [eye height – screen height]/viewing distance]). The viewing direction is a combined effort of neck flexion/extension and angle of gaze performed by the extraocular musculature (Figure 3B).

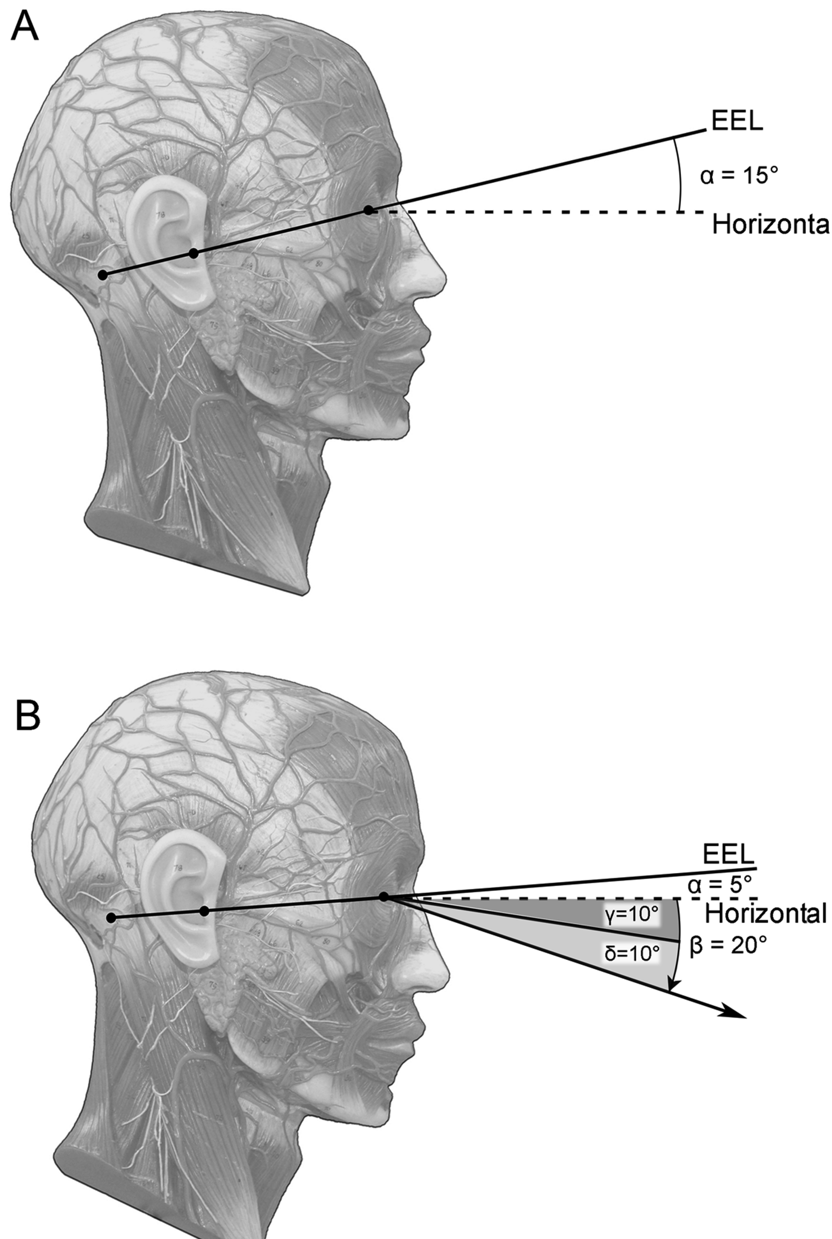


**Figure 3.** Flexion of the head and viewing direction. **A.** Neutral position; the anatomical Ear Eye Line (EEL) is 15 degrees to the horizontal. **B.** Head in 10° flexion; the anatomical EEL is now measured at 5° above the horizontal. Viewing direction (arrow) at angle β is a combined effort of head flexion γ and the gaze angle δ of the eyes.

## Statistical analysis

A power analysis was performed to calculate sample size for paired analysis. To find a 5° difference in flexion and rotation between the groups with a standard deviation of 10°, sample sizes of at least 10 participants are needed, with a type 1 error rate set at 0.05 and power set at 0.80. Because the desired difference and standard deviations were estimates, we performed 16 measurements in each group to avoid type 1 and type 2 errors.
Continuous variables were compared with the Student T-test for paired observations and are presented as mean ± standard deviation. Effect sizes were calculated only for the statistically significant results because differences between the results for the two types of operating room due to sample fluctuation have no clinical relevance. Cohen's effect size d for related samples was used to estimate the magnitude of the difference between the results for the MIS suite and those for the conventional operating room. To avoid overestimation of the effect with Cohen's thresholds, mean differences were standardized by the pooled standard deviation [17]. According to these thresholds, an effect size less than 0.20 indicates a trivial difference, 0.20 to 0.50 a small difference, 0.50 to 0.80 a moderate difference, and 0.80 or more a large difference [18]. Middel et al. [19] showed that effect size reflects clinical relevance. In the current study, an effect size of 0.50 or larger was considered to be a clinically relevant difference between groups. All statistical tests were two-tailed. A p-value less than 0.05 was used for all tests to indicate statistical significance. All statistical analyses were performed using SPSS 13.0.1 for Windows (SPSS, Chicago, IL, USA).

# Results

The neck flexion and rotation of all 48 subjects were successfully analyzed for both the MIS suite and the traditional operating room. Of the 16 teams, 9 (54%) started in the MIS suite. The remainder started in the conventional operating room. All laparoscopic cholecystectomies were completed without any adverse events.
Table 1 shows the results for rotation. A statistically significant reduction in neck rotation was achieved in the MIS suite for the surgeon (5.2°; $p = 0.018$) and the assisting surgeon (29.2°; $p<0.001$). Effect sizes indicated large differences between the performances in the MIS suite and the conventional operating room. The scrub nurse did not significantly reduce her neck rotation in the MIS suite.

**Table 1.** Neck rotation of the participants (mean(sd))

| | Rotation degrees | | | |
|---|---|---|---|---|
| | MIS Suite | Conventional OR | P | ES |
| Surgeon | 5.91 (4.6) | 11.11 (7.5) | 0.018 | 0.83 |
| Assisting surgeon | 9.85 (10.0) | 38.77 (14.0) | <0.001 | 2.37 |
| Scrub nurse | 8.95 (7.7) | 1.08 (6.2) | 0.461 | |

The target value for mean rotation was less than 15 degrees

Table 2 shows the results for flexion, gaze angle, and viewing direction. Neck flexion was significantly improved for the surgeon in the MIS suite, preventing extension of the neck. Paired comparisons for the participating surgeons showed that flexion was increased by 7.2° on the average ($p<0.001$). Also, the viewing direction significantly declined ($p<0.001$). The angle of gaze, accounted for by the extraocular muscles, was not influenced by monitor position ($p = 0.64$). The assisting surgeon did not improve neck flexion or viewing direction in the sagittal plane. The scrub nurse improved neck flexion significantly in the MIS suite, preventing extension of the neck. Paired comparisons for the participating scrub nurses showed that flexion was increased by 7.3° on the average ($p = 0.018$). Also, the viewing direction significantly declined ($p<0.001$). The angle of gaze was not influenced by monitor position ($p = 0.82$). For the surgeon and the scrub nurse, effect sizes indicated large differences in the performances for flexion and viewing direction between the MIS suite and the conventional operating room.

Table 3 shows the results of the questionnaire. On the VAS, the surgeons rated the ergonomic quality of their posture 23 mm more positive in the MIS suite ($p<0.001$).

In the second question, they indicated that they did not experience many complaints in either type of operating room. The questionnaire suggested a slight but statistically significant reduction of musculoskeletal complaints in the MIS suite. The assisting surgeons scored their posture 47 mm more positive in the MIS suite ($p = 0.001$) and also indicated experiencing substantially fewer musculoskeletal complaints in the MIS suite (42 mm; $p = 0.002$). The scrub nurses scored their posture 9 mm better in the MIS suite ($p = 0.008$) and suggested that they experienced minimal but statistically significant reduction in musculoskeletal complaints (10 mm; $p = 0.031$).

**Table 2.** Neck flexion, viewing direction and gaze angle (mean(sd))

| | | Angle in degrees | | | |
|---|---|---|---|---|---|
| | | MIS suite | Conventional OR | P | ES |
| Surgeon | Flexion | -3.52 (3.2) | 3.70 (2.9) | <0.001 | 2.37 |
| | Viewing direction | -12.87 (4.3) | -4.13 (2.6) | <0.001 | 2.46 |
| | Gaze angle | -9.35 (4.2) | -7.83 (7.4) | 0.083 | |
| Assisting | Flexion | 5.43 (7.1) | 6.64 (6.4) | 0.397 | |
| surgeon | Viewing direction | -0.23 (4.8) | -2.02 (4.7) | 0.105 | |
| | Gaze angle | -5.67 (5.8) | -8.67 (4.8) | 0.039 | 0.56 |
| Scrub nurse | Flexion | 0.40 (5.2) | 7.96 (4.8) | <0.001 | 1.51 |
| | Viewing direction | -8.17 (7.1) | -1.20 (2.6) | 0.002 | 1.30 |
| | Gaze angle | -9.86 (6.9) | -9.16 (4.2) | 0.828 | |

The target values for neck flexion were neutral to slightly inclined for the surgeon and neutral for the assisting surgeon and the scrub nurse. Target values for viewing direction were between -10 and -30 degrees for the surgeon and between 0 and -15 degrees for the assisting surgeon and the scrub nurse.

**Table 3.** Two-question VAS questionnaire 0-100mm (mean(sd))

| | | VAS score | | | |
|---|---|---|---|---|---|
| | | MIS suite | Conventional OR | P | ES |
| Surgeon | Posture | 93 (4) | 70 (8) | <0.001 | 3.64 |
| | Complaints | 1 (2) | 10 (9) | 0.004 | 1.38 |
| Assisting surgeon | Posture | 82 (11) | 35 (18) | <0.001 | 3.15 |
| | Complaints | 6 (4) | 48 (22) | 0.002 | 2.66 |
| OR nurse | Posture | 83 (8) | 74 (7) | 0.008 | 1.20 |
| | Complaints | 7 (8) | 17 (14) | 0.031 | 0.88 |

Mean scores measured from a 100mm VAS. Optimal posture = 100mm. No complaints = 0mm

## Discussion and conclusions

The literature provides evidence that physical discomfort during MIS is very common [6, 9]. Complaints concerning the neck and back can be caused by an uncomfortable and static posture in relation to the position of the monitor. Studies examining the most comfortable posture advise a viewing direction straight ahead and at a slightly downward angle [9, 12, 20]. In this monitor configuration, the working posture is the most neutral. Studies examining efficiency of movement and task performance during MIS advise a monitor configuration straight in front of the surgeon and in the direct vicinity of the operating field [10, 15, 21, 22]. This monitor configuration brings the viewing direction back to the direction of work and restores the natural eye–hand–target axis. Optimal monitor positioning is a balance between these two entities to create a work environment that enables the operating team to work efficiently for long periods without experiencing physical discomfort. This may save valuable operating room time and reduce physical overexertion.

To date, we have demonstrated only postural improvement of the cervical spine. Our video analysis system proved to be an accurate and noninvasive means of measuring multiple persons during one procedure at a high frequency in a sterile environment. Most complaints related to the monitor position involve the cervical spine and the upper extremities. However, when multiple working directions are adapted during the procedure, it might be interesting to observe the entire spine.

Because the surgical teams performed their normal tasks during the procedure in both operating rooms, no order effects were expected between the first and the second measurements. For this reason, the current study was very suitable for a crossover design. With this study design, we could eliminate the possibility of covariate imbalances between the study groups, which is very important in posture analysis.

In this study, we chose to observe laparoscopic cholecystectomy because this is a frequently performed and relatively short procedure that has standard and clearly identifiable stages and requires only one working direction.

For this procedure, we demonstrated significant ergonomic benefits of the MIS suite. We expect that these benefits will increase with increasing duration and complexity of the procedure, especially when the surgeon has to work in multiple directions.

In the conventional operating room, we used a single monitor setup for a laparoscopic cholecystectomy because this is the daily practice at MCL. If a second monitor had been used, the neck rotation of the assisting surgeon would have been decreased, with neck extension remaining the same or even increased because our accessory monitor sits on a tall trolley elevating the center of the screen to 177 cm compared with 165 cm using the main trolley.

We used a dedicated MIS suite to demonstrate the ergonomic benefit of monitors connected to a ceiling-mounted suspension system. This feature is not exclusive to the MIS suite concept, but also can be found with other configurations. Many other simpler solutions can be applied to improve the monitor position. Accessory laparoscopic trolleys and small height-adjustable flat screens attached to the side of the trolley could achieve the same ergonomic advantage. However, during more complex procedures that require working in multiple directions, the entire trolley still must be moved to maintain a neutral viewing direction.

The ergonomic benefit of suspended monitors is not the only consideration for hospitals building an MIS suite. Safety, efficiency, and financial aspects also are important and can be improved for a clinician working in an MIS suite. Improved efficiency can reduce expensive operating room time and allow planning of extra procedures. Efficiency is improved because the laparoscopic equipment is operational on demand inside the operating room. This reduces preparation time and may prevent time loss caused by connection errors. During operations, the operating room team can work more efficiently because of improved ergonomics. The laparoscopic equipment is remote controlled by the circulating nurse from her nursing station or by the surgeon using a touch panel or voice control. This may allow a reduction of personnel in the operating room. Safety is improved by reducing connection errors with the permanently installed equipment, and because the equipment is remote controlled, the circulating nurse does not have to approach the sterile field as often. Equipment such as video documentation devices, not directly needed for the patient, can be moved away from the operating field. The power supply, network and audiovisual connections, and supply of gases are delivered through the ceiling-mounted power beams to the equipment from sources outside the operating room. These features reduce the number of hazardous cables and tubes running across the floor. They create more free space in the operating room and contribute to a safe and efficient work environment.

A new MIS suite does not automatically ensure that the ergonomic posture will be improved without special attention to this aspect. The most important condition for improved ergonomics is an operating room staff with some knowledge of ergonomics and the probable causes of posture-related complaints during MIS. Second, the operating room staff must be aware of the possible solutions to these complaints and the way these ergonomic solutions can be achieved in the MIS suite. This requires additional training in ergonomics for everyone working with MIS and technical instructions for everyone using the MIS suite.

Because of the versatile monitor positioning in the MIS suite, a screen may be positioned incorrectly just as easily. Inadequate use of the MIS suite was excluded in this study by optimizing monitor positions for both types of operating room during each procedure.

In conclusion, this study demonstrates that operating rooms with suspended monitors, as in modern MIS suites, can improve the posture of the entire surgical team significantly. Using suspended monitors, the surgeon, the assisting surgeon, and the scrub nurse can stand straight in front of a monitor with minimal neck rotation. With an inclined monitor position, the surgeon's viewing direction and working direction are brought together again, which will enhance his operating performance and efficiency. For the assisting surgeon and the scrub nurse, the monitors can be adjusted to avoid neck extension and rotation.

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# Chapter 4

# Interoperative efficiency in minimally invasive surgery suites

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Surgical Endoscopy 2009; 23: 2332-2337

## Abstract

*Background* Performing minimally invasive surgery (MIS) in a conventional operating room (OR) requires additional specialized equipment otherwise stored outside the OR. Before the procedure, the OR team must collect, prepare, and connect the equipment, then take it away afterward. These extra tasks pose a thread to OR efficiency and may lengthen turnover times. The dedicated MIS suite has permanently installed laparoscopic equipment that is operational on demand. This study presents two experiments that quantify the superior efficiency of the MIS suite in the interoperative period.

*Methods* Preoperative setup and postoperative breakdown times in the conventional OR and the MIS suite in an experimental setting and in daily practice were analyzed. In the experimental setting, randomly chosen OR teams simulated the setup and breakdown for a standard laparoscopic cholecystectomy (LC) and a complex laparoscopic sigmoid resection (LS). In the clinical setting, the interoperative period for 66 LCs randomly assigned to the conventional OR or the MIS suite were analyzed.

*Results* In the experimental setting, the setup and breakdown times were significantly shorter in the MIS suite. The difference between the two types of OR increased for the complex procedure: 2:41 min for the LC ($p<0.001$) and 10:47 min for the LS ($p<0.001$). In the clinical setting, the setup and breakdown times as a whole were not reduced in the MIS suite. Laparoscopic setup and breakdown times were significantly shorter in the MIS suite (mean difference, 5:39 min; $p<0.001$).

*Conclusion* Efficiency during the interoperative period is significantly improved in the MIS suite. The OR nurses' tasks are relieved, which may reduce mental and physical workload and improve job satisfaction and patient safety. Due to simultaneous tasks of other disciplines, an overall turnover time reduction could not be achieved.

# Introduction

Laparoscopic procedures require specialized equipment that usually is not permanently present in a conventional operating room (OR). Before laparoscopic procedures, OR personnel must collect the laparoscopic equipment, stationed on large trolleys, from its storage facility and install it in the OR. This can be a time-consuming task. The average general surgery OR is not designed to house this equipment, leading to crowded workplaces, floors cluttered with tubing and wiring, operative inefficiencies, and safety problems for patients and staff [1].

In the early 1990s, the concept of the dedicated minimally invasive surgery (MIS) suite was first introduced as a means to solve these problems and others associated with MIS. The modern MIS suite is a fully integrated OR in which the laparoscopic equipment and multiple flat screen monitors are permanently installed to be operational on demand inside the OR. The equipment is installed in columns attached to a ceiling-mounted suspension system that facilitates versatile positioning apart from the monitors. All the tubing and wiring are concealed inside the suspension system and led out of the OR through the ceiling. The laparoscopic equipment can be remotely controlled by the operating surgeon using voice control or by the circulating nurse using a touch panel at a control station away from the sterile field.

A MIS suite is designed to reduce OR clutter and staff workload; increase comfort, safety, and OR efficiency; and enhance ergonomics and OR team performance [2–4]. Many hospitals around the world have already invested, or are investing, in one or multiple MIS suites, but to date, no evidence has been provided to show the actual effect this type of OR has on efficiency in everyday practice.

We therefore conducted a study comparing setup and breakdown times of the MIS suite and the standard OR for both complex and standard laparoscopic procedures. We performed these measurements in an experimental setting and in daily practice.

# Methods

## Study design

This study aimed to determine the turnover time reduction in the MIS suite compared with the conventional OR for complex and standard laparoscopic procedures. The time span between two operations is dependent on many factors and disciplines. For an accurate estimation of the exclusive contribution the MIS suite makes to interoperative efficiency, we decided first to perform measurements in an experimental setting. Second,

we analyzed interoperative periods in a clinical setting to evaluate whether the actual interoperative periods, including nonsurgical activities, also were reduced with the improved efficiency in the MIS suite.
In the experimental situation, a crossover design was used. The times required to set up and to break down an operative setting for a standard laparoscopic cholecystectomy (LC) and a complex laparoscopic sigmoid resection (LS) were recorded. The setup time was defined as the time required to prepare an empty OR for a procedure up until all laparoscopic and video equipment was installed and operational. The breakdown time was defined as the time required to dismantle the laparoscopic and video equipment and clean up the OR up until the OR was empty and ready for the next procedure.
The clinical part of this study measured the turnover times in daily practice for LCs. The pre- and postoperative periods were divided into the same identifiable stages as in the experimental setting. After data collection, the clinical results were compared between the different types of OR and with the experimental results.

## Operating room setup

Both types of OR are situated in the same complex, have the same size, and meet the latest standards. The storage room for the laparoscopic trolleys used in the conventional OR is centrally located in the operating complex. For both the experimental and the clinical measurements we used OR's adjacent to the storage room.
In the experimental situation, three randomly chosen teams of two OR nurses had to set up and break down the operative setting. The one OR nurse performed the tasks of the sterile scrub nurse, whereas the other performed the tasks of the circulating nurse. In random order, each OR nurse performed each task in both types of OR, so we had six measurements per type of procedure per type of OR in which each nurse was her own matched control.
All the participants were highly qualified laparoscopic OR nurses especially trained by ''the endoscopic team.'' This group of nurses routinely performs a wide variety of laparoscopic procedures in both the MIS suite and the conventional OR. Table 1 shows the equipment necessary to perform the procedures. The setup for the standard LC required less equipment than the setup for the more complex LS.
In the clinical part of the study, 66 consecutive LCs were analyzed. In randomized order, 36 were assigned to the MIS suite and 30 to the conventional OR on the day before the procedure. Standard equipment, as shown in table 1, was used for each procedure. In the MIS suite, two flat screen displays were used compared with one cathode ray tube (CRT) monitor on top of the single laparoscopic trolley in the conventional OR. Figure 1A and B delineate the floor plan of the operative setup inside the OR.

**Table 1:** Equipment needed and its location to perform a laparoscopic cholecystectomy (LC) and a laparoscopic sigmoid resection (LS) in the MIS suite (MISS) and the conventional OR (Conv). Items marked with * are not permanently present in the OR.

| Equipment | LC MISS | LC Conv | LS MISS | LS Conv |
|---|---|---|---|---|
| Insufflation | Boom 1 | Trolley * | Boom 1 | Trolley 1 * |
| Camera | Boom 1 | Trolley * | Boom 1 | Trolley 1 * |
| Light source | Boom 1 | Trolley * | Boom 1 | Trolley 1 * |
| Documentation | Control station | Trolley * | Control station | Trolley 1 * |
| Electrocautery | Boom 2 | Boom | Boom 2 | Boom |
| Monitor 1 | Suspended | Trolley * | Suspended | Trolley 1 * |
| Monitor 2 | Suspended | | Suspended | Trolley 2 * |
| Ultracision | | | Boom 2 | Cart 1 * |
| Suction/irrigation | | | Cart | Cart 2 |

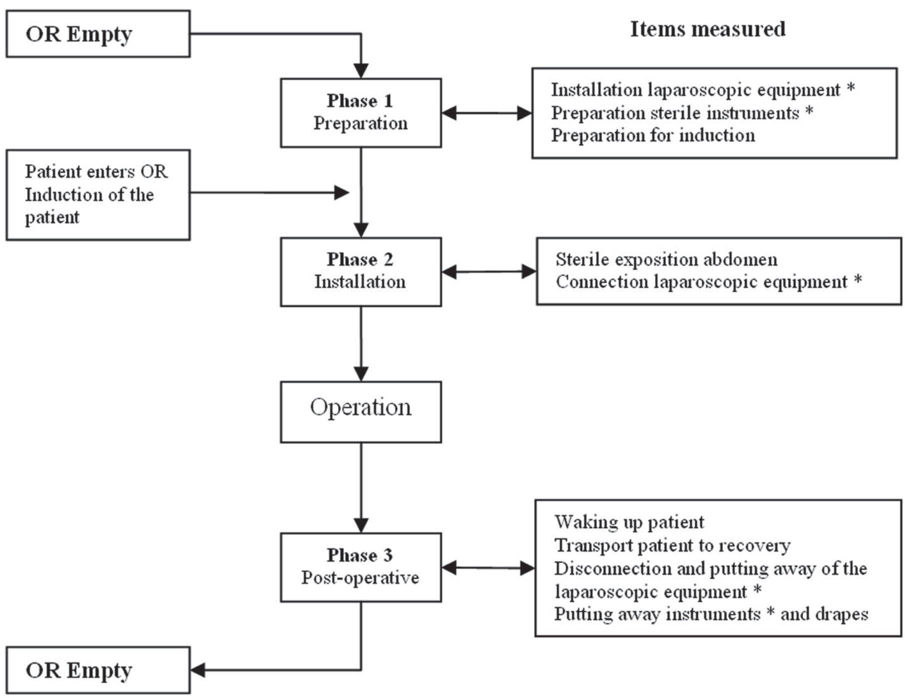


**Figure 1.** The different phases of a laparoscopic procedure with the tasks performed during these phases. The items marked with * were measured in the experimental setting. All items were measured in the clinical setting.

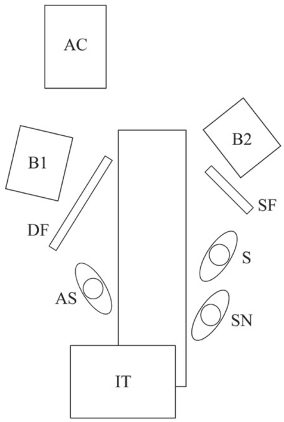


**Figure 2a.** Setup for a laparoscopic cholecystectomy in the MIS suite. S: Surgeon, SN: Scrub Nurse, AS: Assisting Surgeon, IT: Instrument table, DF: double flat screen, SF: single flat screen, AC anesthesia console, B1: Boom 1, B2: Boom 2.

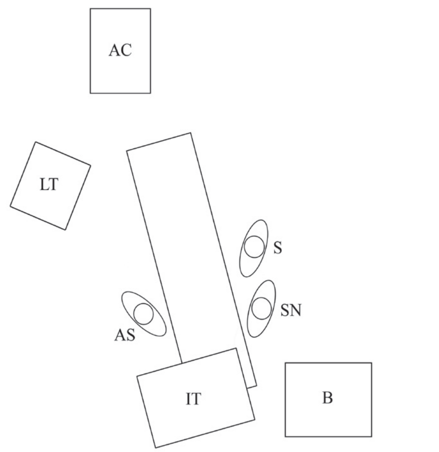


**Figure 2b.** Setup for a laparoscopic cholecystectomy in the conventional OR. S: Surgeon, SN: Scrub Nurse, AS: Assisting Surgeon, IT: Instrument table, LT: laparoscopic trolley, AC anesthesia console, B: Boom.

## Data collection

Within one complete time cycle of a laparoscopic procedure from empty OR before the procedure to empty OR after the procedure, we identified three interoperative phases (Figure 1). Two phases were identified in the preoperative period. Phase 1 comprised preparation of the OR, the monitors, and the laparoscopic equipment up until the patient could enter the room. After the patient was asleep and draped, phase 2 comprised the installation and connection of the camera, light source, insufflator, and electrocautery devices as well as switching on the monitors. This phase was completed when the equipment was fully operational and the camera image was visible on the monitors. After completion of the laparoscopic procedure, which we did not analyze, the postoperative period, phase 3, consisted of breaking down the laparoscopic instruments and equipment and returning them to the storage facility. Phase 3 was completed when the OR was empty and ready for the next procedure.
In the experimental situation, the OR nurses were carefully instructed not to rush and to perform their tasks in a usual pace and fashion. Phases 1, 2, and 3 were simulated. All the measurements were performed by one observer, who used a stopwatch to time the phases. After each phase, the time measurements were instantly processed on a laptop computer.

The clinical measurements were performed without instruction of the OR personnel. The same phases were identified and recorded. In addition to the laparoscopic work performed by the surgical team in each phase, there also were other tasks for the surgical team and the anesthesia team. These other tasks were not influenced by the type of OR but did require a certain amount of time. The duration of each complete phase was measured by recording the start and completion times. To appreciate the amount of time required to perform only the separate laparoscopic tasks within each phase, the timer function of a stopwatch was used for this more specific measurement.
Two observers collected the data. The first observer measured 45 consecutive procedures randomly assigned to the different types of OR (25 in the MIS suite and 20 in the conventional OR) and also conducted the measurements in the experimental setup. The second observer performed the last 21 consecutive procedures (11 in the MIS suite and 10 in the conventional OR). Although the observers measured two different samples, we compared the laparoscopic setup and breakdown times of the two observers per type of OR to estimate the reproducibility and observer bias of the data.

### Statistical analysis

For the experimental setting, mean outcomes and their standard deviations were compared per OR nurse between the MIS suite and the conventional OR using the t-test for paired observations. For the clinical setting, mean outcomes were compared using the independent samples *t*-test. The samples for each type of OR measured by the two observers also were compared using the independent samples *t*-test. All statistical tests were two-tailed. A *p* value less than 0.05 was used for all tests to indicate statistical significance. All statistical analyses were performed using SPSS 14.0.1 for Windows (SPSS, Chicago, IL, USA).

## Results

In the experimental setting, the three teams of OR nurses performed their tasks in at normal pace and provided six paired data sets per type of procedure per type of OR. Table 2a shows the results for the LC in the experimental setting. The execution times for setup (phase 1) and breakdown (phase 3) were significantly shorter in the MIS suite than in the conventional OR. After the equipment was set up, the connection time (phase 2) did not differ between the two types of OR. The execution times of the complete preoperative setup (phases 1 and 2) and the overall execution time (phases 1, 2, and 3) also were significantly shorter in the MIS suite. The mean difference in the overall execution time was 2:41 min (standard error (SE), 15.7s; $p<0.001$).

**Table 2a:** Execution times (mean (±SD)) in the MIS suite (MISS) and the conventional OR (Conv) in the experimental setting for the different phases of the LC as indicated in Figure 1.

| Lap Choly | Mean MISS | Mean Conv | Mean diff | SE | P |
|---|---|---|---|---|---|
| Setup phase 1 | 1:01.1 (±21.0) | 2:28.2 (±11.4) | 1:27.1 | 10.9 | <0.001 |
| Setup phase 2 | 1:35.6 (±11.9) | 1:40.6 (±24.5) | 5.0 | 9.4 | 0.621 |
| Setup (1+2) | 2:36.7 (±22.4) | 4:08.8 (±32.0) | 1:32.1 | 11.7 | 0.001 |
| Break down (3) | 1:37.2 (±23.9) | 2:46.2 (±9.2) | 1:09.0 | 10.7 | 0.001 |
| Total (1+2+3) | 4:13.8 (±39.8) | 6:55.0 (±35.7) | 2:41.2 | 15.7 | <0.001 |

**Table 2b:** Execution times (mean (±SD)) in the MIS suite (MISS) and the conventional OR (Conv) in the experimental setting for the different phases of the LS as indicated in Figure 1.

| Lap Sigmoid | Mean MISS | Mean Conv | Mean diff | SE | P |
|---|---|---|---|---|---|
| Setup phase 1 | 1:14.0 (±18.9) | 6:21.0 (±40.1) | 5:07.0 | 18.1 | <0.001 |
| Setup phase 2 | 1:54.6 (±38.3) | 2:54.0 (±41.4) | 59.4 | 7.2 | <0.001 |
| Setup (1+2) | 3:08.6 (±39.3) | 9:14.9 (±57.2) | 6:06.3 | 22.9 | <0.001 |
| Break down (3) | 2:06.7 (±26.6) | 6:47.7 (±19.1) | 4:41.0 | 12.7 | <0.001 |
| Total (1+2+3) | 5:15.3 (±62.2) | 16:02.6 (±58.3) | 10:47.3 | 26.1 | <0.001 |

Table 2b shows the results for the LS in the experimental setting. All the execution times were significantly shorter in the MIS suite. The mean difference in the overall execution time was 10:47 min (SE, 26.1 s; $p<0.001$).

In the clinical setting, 66 LCs were analyzed. All 66 LCs were performed for uncomplicated symptomatic gallbladder stones. There were no major intraoperative complications or conversions to open cholecystectomy.

**Table 3:** Execution times (mean (±SD)) in the MIS suite (MISS) and the conventional OR (Conv) in the clinical setting. Stages marked with * indicate execution times for laparoscopic tasks only as indicated in Figure 1.

| Daily practice | Mean MISS | Mean Conv | Mean diff | SE | P |
|---|---|---|---|---|---|
| Phase 1* | 39.9 (±17.4) | 2:40.4 (±33.4) | 2:00.5 | 6.4 | <0.001 |
| Phase 2* | 56.5 (±17.1) | 1:56.7 (±20.8) | 1:00.2 | 4.7 | <0.001 |
| Pre-op (1+2)* | 1:36.4 (±19.9) | 4:37.1 (±33.8) | 3:00.7 | 6.7 | <0.001 |
| Pre-op (1+2) | 14:27.8 (±3:33.8) | 16:20.8 (±3:38.5) | 1:53.0 | 1:04.8 | 0.089 |
| Procedure | 1:05:53.8 (±25:39.6) | 1:04:01.7 (±20:19.4) | 1:52.1 | 5:47.0 | 0.748 |
| Phase 3* | 59.1 (±15.8) | 3:37.0 (±52.8) | 2:37.9 | 9.3 | <0.001 |
| Phase (3) | 6:19.1 (±2:28.9) | 7:01.8 (±2:53.5) | 42.7 | 39.7 | 0.293 |
| Total (1+2+3)* | 2:35.6 (±26.6) | 8:14.1 (±54.0) | 5:38.5 | 10.2 | <0.001 |
| Total (1+2+3) | 20:46.9(±4:41.6) | 23:22.6 (±5:18.6) | 2:35.7 | 1:29.6 | 0.146 |

Table 3 shows the execution times for the different phases as a whole and for the laparoscopic tasks only. The execution times for the entire preoperative phases were not significantly different between the two types of OR. Also, the execution times for the procedure and the postoperative stage were not significantly different. The laparoscopic execution times, unlike the entire phase, were significantly shorter in the MIS suite during each phase. The mean difference in the overall interoperative laparoscopic execution time was 5:39 min (SE, 10.2 s; $p<0.001$).

The interobserver reproducibility was evaluated for the laparoscopic setup (phases 1 and 2) and for the postoperative laparoscopic phase (phase 3) in the different types of OR (Table 4). The execution times for the different samples from the two observers showed no significant differences.

**Table 4.** Comparison of the measurements of the observers in the MIS suite (MISS) and the conventional OR (Conv). Phases comply with the tasks as indicated in Figure 1.

| Observers | Observer 1 | Observer 2 | Mean diff | SE | P |
|---|---|---|---|---|---|
| Lap setup (1+2)* MISS | 1:34.7 | 1:40.4 | 5.7 | 7.2 | 0.440 |
| Lap setup (1+2)* Conv | 4:35.2 | 4:40.9 | 5.7 | 13.3 | 0.671 |
| Phase 3* MISS | 58.6 | 1:00.2 | 1.6 | 5.8 | 0.792 |
| Phase 3* Conv | 3:47.3 | 3:16.3 | 31.0 | 20.0 | 0.132 |
| Total (1+2+3)* MISS | 2:33.4 | 2:40.6 | 7.2 | 9.7 | 0.462 |
| Total (1+2+3)* Conv | 8:22.5 | 7:57.2 | 25.3 | 20.7 | 0.232 |

## Conclusions and discussion

Performing MIS procedures in a conventional OR requires the application of equipment not commonly present in the OR. Before the start of the laparoscopic procedure, OR personnel must collect the equipment, stationed on large trolleys, from its storage facility. Electricity, video cables, and carbon dioxide supply must be connected and inspected before usage. These tasks are physically burdensome and time demanding, and they are prone to connection errors and malfunctioning of the equipment that do occur in the majority of laparoscopic cases [5].

This study demonstrates that the time necessary to install, set up, and break down laparoscopic equipment for MIS interventions can be significantly reduced in a dedicated MIS suite. The time reduction increases with the complexity of the procedure because complex procedures require the setup of additional monitors and other equipment already present and ready for use in the MIS suite.

The experimental data suggest that an average time reduction of 2:41 min for a standard procedure and 10:47 min for a more complex procedure can be achieved per procedure in the MIS suite.

The results of the clinical measurements, however, could not translate the experimental results into a significant time reduction for the interoperative period. Our clinical data suggest a mean difference in the entire interoperative period of 2:36 min in favor of the MIS suite (Table 3). Due to the relatively long phases compared with the laparoscopic tasks alone, which required only a fraction of the recorded time, the standard deviations and standard errors were too large for statistical significance to be reached. A look at the execution times for the laparoscopic tasks alone shows a significant time reduction for each interoperative phase, resulting in a potential overall time reduction of 5:39 min for the surgical OR team during the interoperative period.

Obviously, in our hospital, the duration of the interoperative period depends not only on the tasks and pace of the surgical OR team but also on the pace of the anesthesia team. Only when they also can streamline their workflow inside the OR by means of protocolling their work or performing certain tasks before the patient enters the OR can the full efficiency profit of the MIS suite be achieved.

The results of the two observers who performed the measurements in daily practice were very similar, suggesting that this is a reliable and replicable way of recording interoperative execution times. Because the observers measured different samples, a true interobserver reliability could not be calculated.

In the clinical setting, we did not measure the possible turnover time reduction for complex laparoscopic procedures. Because the variance in the complete preoperative preparation times and the postoperative breakdown times was already very large for LCs, we realized that this variance would only increase during the more complex procedures, mostly due to all the additional nonsurgical tasks.

Also, we did not examine the effect of the MIS suite on intraoperative efficiency. Luketich et al. [6] performed a study to evaluate the workload reduction for the circulating OR nurse by the use of voice control, a feature of the MIS suite. Their results demonstrate that during laparoscopic fundoplication, the intraoperative workload of the OR nurse can be reduced by 4.35 min and that satisfaction scores for both the surgeon and the nurse are significantly improved when voice control is used. However, in their article, they did not mention the effect of voice control on their procedure time.

Features other than voice control also are likely to contribute to improved efficiency during the procedures. Monitors installed on ceiling-suspended beams facilitate an ergonomic viewing direction [4, 7]. When viewing direction is optimized, it is possible to perform laparoscopic tasks more efficiently and effectively [8, 9].

The MIS suite concept with its permanently installed laparoscopic equipment available on demand allows a more efficient workflow during the interoperative period for the OR team. Although to date this has not led to a significant time reduction for the overall interoperative period, we did demonstrate that the workload of the OR nurses is significantly reduced. A reduced workload may contribute to job satisfaction and reduce mental and physical stress. Also, safety and ergonomics may be improved for both the OR team and the patients. Because OR nurses no longer need to transport the heavy equipment through the OR complex, they have more time available to prepare the patient and the OR for the upcoming procedure

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# Chapter 5

# The learning effect of intraoperative video-enhanced surgical procedure training

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## Abstract

*Background* The transition from basic skills training in a skills lab to procedure training in the operating theater using the traditional master-apprentice model (MAM) lacks uniformity and efficiency. When the supervising surgeon performs parts of a procedure, training opportunities are lost. To minimize this intervention by the supervisor and maximize the actual operating time for the trainee, we created a new training method called INtraoperative Video-Enhanced Surgical procedure Training (INVEST).

*Methods* Ten surgical residents were trained in laparoscopic cholecystectomy either by the MAM or with INVEST. Each trainee performed six cholecystectomies that were objectively evaluated on an Objective Structured Assessment of Technical Skills (OSATS) global rating scale. Absolute and relative improvements during the training curriculum were compared between the groups. A questionnaire evaluated the trainee's opinion on this new training method.

*Results* Skill improvement on the OSATS global rating scale was significantly greater for the trainees in the INVEST curriculum compared to the MAM, with mean absolute improvement 32.6 versus 14.0 points and mean relative improvement 59.1 versus 34.6% ($P = 0.02$).

*Conclusion* INVEST significantly enhances technical and procedural skill development during the early learning curve for laparoscopic cholecystectomy. Trainees were positive about the content and the idea of the curriculum.

# Introduction

Laparoscopic surgery requires complex techniques and skills that are not employed in open surgery. The instruments provide limited haptic feedback, lack degrees of freedom, and move inverted inside the abdomen [1, 2]. Furthermore, video monitors that provide a 2-dimensional projection of the operating field impair depth perception and are moved away from the patient [3, 4]. Surgeons and residents in surgery have to master these technical skills and challenges before they can perform any laparoscopic procedure appropriately and safely.
How to teach laparoscopic surgery to residents in a safe and efficient way is the topic of many debates, conventions, and research projects [5]. Rasmussen's model of human behavior in laparoscopic training, as described by Wentink et al., identified three levels of behavior that have to be trained, namely, skill-based behavior, rule-based behavior, and knowledge-based behavior [6]. Skill-based behavior in laparoscopy is best described as the set of technical skills that are needed in every procedure and comprises motor movements that are continuously regulated by feedback systems. Rule-based behavior is more complex and comprises specific sets of procedural steps that are performed according to stored rules. A sign serves to activate or trigger a stored rule. For example, having applied ligation clips on the cystic duct and artery in a laparoscopic cholecystectomy is the sign that triggers the rule that these structures can be transected next. Knowledge-based behavior is encountered when no rules are available, for instance, when a complication or an unexpected anatomical variation is encountered. Different plans of behavior are evaluated against the anticipated goal.
Traditionally, surgery has been taught following the master-apprentice model (MAM). In this model the surgical trainee learns to perform surgical procedures under the supervision of a qualified surgeon. The supervising surgeon instructs the trainee and, when necessary, he temporarily takes over the procedure to show a difficult step. Nowadays, it is no longer accepted that a novice learns skill based behavior on patients as there are validated training platforms available for practicing basic skills for both conventional and laparoscopic surgery that avoid patients being exposed to early learning curves [7, 8]. Basic laparoscopic motor skills can be practiced repeatedly on box trainers, virtual reality (VR) trainers, and augmented reality (AR) trainers [9, 10]. VR trainers allow repeated practice of various exercises and record parameters such as instrument path length, collisions, and time to objectively score the trainee's performance on these exercises. Some VR trainers are compact and use ''plug and play'' technology so they can be taken home for practice. However, a disadvantage of most VR trainers is the lack of haptic feedback for instrument and tissue handling [11]. Box trainers, on the other hand, provide haptic feedback and can be used for both basic skills and for procedure training using cadaver organs, but they require the use of surgical instruments and disposable materials [12].
Besides technical skills, a trainee has to acquire knowledge of the procedure itself, knowledge of the pitfalls of the procedure, and coping strategies when a problem

presents itself, skills defined by Rasmussen as rule-based and knowledge-based behaviors [6]. In general, teaching these types of behavior is more complex and costly than teaching skill-based behavior. Animal model training and cadaver training are very helpful, but also resource intensive and not available on demand. Books, internet courses, and instruction videos can provide important fundamental knowledge of an illness and its surgical treatment [13].

However, the most important element in training a specific surgical procedure remains the hands-on training on a real patient with an experienced surgeon at the trainee's side. At the beginning of a trainee's learning curve, it is likely that the supervising surgeon frequently takes over the procedure to demonstrate case-specific rule-based and knowledge-based behavior. A major disadvantage of this training model is that steps can be performed only once per procedure by either the trainee or the supervising surgeon. When the supervisor takes over, that part is lost to the trainee who has to wait for the next operation to perform the step himself. To minimize the frequency of this intervention by the supervisor and maximize the actual operating time for the trainee, we created a new training method called INtraoperative Video-Enhanced Surgical procedure Training (INVEST). This method implements instruction videos to train rule-based and knowledge-based behaviors by demonstrating key elements and essential tips and tricks of the procedure step-by-step and on-demand without the need for the supervisor to demonstrate them by taking over. Therefore, these steps are preserved and can be performed by the trainee.

In the current study we investigated the effect of INVEST on the early learning curve in surgical procedure training inside the operating theater by showing short intraoperative instruction videos to surgical trainees.

# Methods

## Study design

This study was a randomized controlled trial with repeated measurements among trainees who were randomly assigned to a series of laparoscopic cholecystectomies utilizing either INVEST or the usual MAM. Intraindividual improvement of surgical skills was evaluated across students trained in either group. We preferred a baseline follow- up study design as it rules out a large number of confounding factors that are likely to occur when comparing separate outcomes between independent groups. Furthermore, we controlled for equal levels of surgical skills at baseline in order to avoid differences in outcome that are due to initial differences among participants.

## Procedure

The INVEST instruction video was created in conformity with the guidelines for laparoscopic cholecystectomy as formulated by the Association of Surgeons of the Netherlands [14]. These guidelines are similar to the guidelines formulated by the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and the European Association for Endoscopic Surgery (EAES), with the addition of the importance of the Critical View of Safety (CVS) [15]. Chronologically, all the separate steps of the procedure that are described in the guidelines were clustered into seven clearly identifiable stages: (1) open introduction of the first trocar, (2) accessory trocar placement, (3) opening of the peritoneal envelope, (4) creating the CVS, (5) clipping and division of cystic duct and artery, (6) retrograde cholecystectomy, and (7) gallbladder removal and closure. For each of the seven stages a 1-min video clip was created, demonstrating anatomical landmarks, key elements, and operative techniques essential to that particular phase of the procedure. Video clips were displayed on demand on a second screen next to the operative screen when the trainee was ready for the next step of the procedure. For safety reasons, neither the trainee nor the supervising surgeon was allowed to continue the procedure while the instruction video was playing. After completion of each video clip, a written summary appeared and was displayed on the accessory screen while the trainee performed the next step.

## Trainee selection

Ten trainees were included in this study. All trainees were registered residents in surgery, were in the early phase of their training, and resided at the department of surgery at Leeuwarden Medical Center. Criteria for inclusion were at least 6 months of experience in open surgical techniques and the successful completion of a training course in basic surgical skills. Exclusion criteria were any hands-on experience with laparoscopic cholecystectomies and a cumulative experience of more than five cases in other laparoscopic procedures.

## Trainee preparation

Since the trainees had no previous experience in laparoscopic techniques, they also had no practical experience with the basic motor skills that are unique to laparoscopic procedures. These skills have to be mastered before anyone can be safely and efficiently trained in a specific laparoscopic procedure. Therefore, before randomization, all residents scheduled for this study developed their basic laparoscopic skills on the SIMENDO laparoscopy trainer (Simendo, Rotterdam, The Netherlands). This validated VR simulator has a variety of exercises and is supplied with a proficiency-based technical skills training curriculum [16]. Successful completion of the SIMENDO curriculum indicates an

adequate level of proficiency in basic laparoscopic technical skills to allow safe participation in laparoscopic procedures on humans [17]. As an additional result of the curriculum, the technical skills of all the trainees were calibrated at an equal level.
After completing the SIMENDO curriculum, residents were randomly assigned to one of the two arms of this study by drawing a sealed envelope. In both groups, each resident performed six laparoscopic cholecystectomies within 2 weeks. Residents prepared themselves for these procedures in standard fashion using textbooks, anatomy books, and online information. During the procedure itself, the control group was trained using MAM. The experimental group, in addition to being supervised by a qualified surgeon, was trained with INVEST.

## Patient selection and supervision

Patients with uncomplicated symptomatic gallstone disease were selected for this study. All patients were asked to give informed consent that a resident would perform the procedure under the supervision of a qualified surgeon. Since the procedure itself did not differ between the experimental and control groups, informed consent was not needed for using INVEST.
Three dedicated laparoscopic surgeons were randomly assigned to supervise the procedures in both groups. They were conversant with the latest guidelines and approved the content of the instruction video. The supervising surgeons were not informed of the progression of the trainee in the course of the six cholecystectomies nor were they informed of previous scores. The surgeons guarded the safety and the flow of the procedure, they gave verbal instructions, and, when necessary, they temporarily took over the procedure. The time and reason for temporarily taking over the procedure was decided on the supervising surgeon's professional autonomy.

## Operating theater setup

All procedures were performed in dedicated minimally invasive surgery (MIS) suites. An MIS suite is a fully integrated operating room (OR) in which laparoscopic equipment and multiple flat-screen monitors are permanently installed to be operational on demand. In the INVEST setting, two monitors were facing the operator and the supervisor, providing an ergonomically safe posture. One monitor displayed the operative image and the other was used for the instruction video. A third monitor displayed the operative image for the scrub nurse. A research fellow who was present during the procedure played the instruction video on demand from a computer that was linked to the designated flat screen monitor.

## Objective Structured Assessment of Technical Skill (OSATS)

After each procedure, the supervising surgeon evaluated the skills of the trainee on a modified and translated version of the seven-question global rating scale that is used as part of the objective structured assessment of technical skill (OSATS) as described by Martin et al. [18]. This modified OSATS global rating scale is used nationwide and is part of the mandatory digital portfolio for every resident in surgery in The Netherlands. Using a 10-point scale, it grades the trainee on seven important elements of any operation, concerning a combination of skill-based, rule-based, and knowledge-based behaviors: (1) respect for tissue, (2) time and motion, (3) instrument handling, (4) knowledge of instruments, (5) use of assistants, (6) flow of operation, and (7) knowledge of the procedure.

## Trainee's opinion questionnaire

After completion of the six cholecystectomies, the trainees in the INVEST group were invited to give their opinion of the training method via a brief questionnaire. To assess the attitude toward INVEST among participants who were not acquainted with it in practice, the instruction video was also shown to the trainees in the MAM group. These trainees were also invited to fill out this questionnaire. The questionnaire comprised seven statements that had to be rated on a 5-point Likert scale where 1 = totally disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = totally agree.

## Statistical methods

To evaluate the effect of INVEST, we were interested in the improvement of skills during the training curriculum. The individual OSATS scores for each procedure are snapshots and do not represent a learning curve. Therefore, we used the OSATS score of the first procedure as a baseline and calculated the improvement from the baseline during the following procedures. For each trainee, the absolute improvement on the OSATS score was calculated for each of the seven individual items and for the complete OSATS scale. In addition, we calculated the relative improvement on the OSATS scale that estimates the maximum score each trainee was able to achieve. With this relative improvement we estimated the percentage that each trainee improved from the first OSATS score (procedure 1) toward the maximum OSATS score at follow-up (procedure 6). Relative improvement in the seven OSATS skills and overall OSATS scale was calculated as follows:

$$\frac{\text{Final OSATS score (procedure 6) – initial OSATS score (procedure 1)}}{\text{Max. achievable OSATS score – initial OSATS score (procedure 1)}} \times 100\%$$

## Reliability

The reliability of the seven-item modified OSATS scale was examined with the internal consistency coefficient Cronbach's alpha [19]. Since Cronbach's alpha is dependent on the number of items in the scale and on the mean inter-item correlation (MIIC), one can achieve a high reliability estimate by having either many items or highly intercorrelated items (or a combination of the two) [20, 21]. According to the guidelines by Briggs and Cheek [22], the MIIC should fall in an optimal range between 0.20 and 0.50 but should not be less than 0.15 [20, 22, 23]. Therefore, taking the upper value of the range, a MIIC C 0.25 seems reasonable. For the seven-item OSATS global rating scale in this study, a Cronbach's alpha coefficient of 0.70 was minimally acceptable. Given the small sample size, the differences in absolute and relative improvements in skills between the INVEST group and the master-apprentice group were compared with the nonparametric Wilcoxon Mann–Whitney test for ordinal data. Effect sizes were calculated only for statistically significant differences, as it makes no sense to estimate clinical relevance of a result that is based on random variation. Cohen's effect size (ES) for independent samples was used to estimate the magnitude of these differences [24]. According to Cohen's thresholds, an ES<0.20 indicates a trivial difference, 0.20–0.50 a small difference, 0.50–0.80 a moderate difference, and >0.80 a large difference.

# Results

Ten trainees were randomly assigned to the two arms of the study, with no dropout after inclusion. Each trainee successfully completed the basic skills training curriculum on the SIMENDO to the preset level of proficiency before randomization. There were no differences between the groups with respect to training time to acquire the proficiency level. Each resident performed six laparoscopic cholecystectomies within the set period of 2 weeks. Each procedure was evaluated by the supervising surgeon using an OSATS global rating scale. There were no technical problems with displaying the instruction video in the INVEST group.

Reliability of the OSATS global rating scale was determined. The OSATS consists of seven items, and summed scores of these items indicate the extent of performance of technical skills. A lower overall score means a poor performance while a higher score indicates good to excellent performance. The internal consistency of the seven-item OSATS overall performance scale was good and yielded a Cronbach's alpha of 0.88.

The OSATS scores for the first procedure were not statistically different between the groups. Analysis of the absolute and relative improvements in the seven separate skills on the OSATS global rating scale indicated a statistically significant ($P < 0.05$) and clinically relevant (ES > 0.80) difference in skills acquisition in favor of the INVEST group for the following skills: time and motion, use of assistants, flow of operation, and knowledge of the procedure (Table 1).

**Table 1.** Absolute and relative improvement on the 7-item OSATS global rating scale for the separate items and the sum score in the INVEST group and the MAM group.

| OSATS | INVEST | | Master-Apprentice Model | | ES | z/p |
|---|---|---|---|---|---|---|
| | Absolute improvement mean ± SD | Relative improvement mean(%) ± SD | Absolute improvement mean ± SD | Relative improvement mean(%) ± SD | | |
| Respect for tissue | 3.2 ± 2.2 | 45.0 ± 26.5 | 2.0 ± 1.3 | 27.9 ± 14.5 | | -1.2 / 0.25. |
| Time and motion | 3.8 ± 1.1 | 49.2 ± 9.4 | 2.0 ± 0.0 | 28.3 ± 4.6 | 2.82 | -2.5 / 0.02 |
| Instrument handling | 5.4 ± 1.3 | 64.0 ± 12.9 | 2.8 ± 1.9 | 39.2 ± 24.2 | | -1.8 / 0.07 |
| Knowledge of instruments | 4.6 ± 1.9 | 57.1 ± 16.6 | 3.2 ± 1.8 | 48.1 ± 27.8 | | -0.53 / 0.60 |
| Use of assistants | 5.0 ± 1.0 | 60.6 ± 15.0 | 1.2 ± 2.2 | 21.2 ± 18.5 | 2.34 | -2.3 / 0.02 |
| Flow of operation | 5.4 ± 1.3 | 62.8 ± 14.9 | 1.6 ± 2.5 | 27.5 ± 20.2 | 1.99 | -2.2 / 0.03 |
| Knowledge of the procedure | 5.2 ± 1.3 | 69.5 ± 7.6 | 1.2 ± 2.5 | 31.0 ± 26.5 | 1.97 | -2.2 / 0.03 |
| Sumscore OSATS | 32.6 ± 6.5 | 59.1 ± 9.8 | 16.4 ± 6.1 | 34.6 ± 10.8 | 2.38 | -2.4 / 0.02 |

The absolute and relative skill improvements on the complete OSATS global rating scale were also significantly higher in the INVEST group (Table 1). The relative improvement during the six procedures is graphically displayed in Figure 1.

The trainees in the INVEST group totally agreed with the statements that intraoperative video training is fun, it has a positive effect on the learning curve, and it is a uniform means of learning laparoscopic cholecystectomy. They agreed on the statements that they were allowed to do more steps of the procedure, the supervisor had to intervene less frequently during the procedure, and they would also like to have this type of training for other procedures. They were neutral on the statement that INVEST would be useful after six procedures. The answers in the MAM group were similar and not statistically different (Table 2).

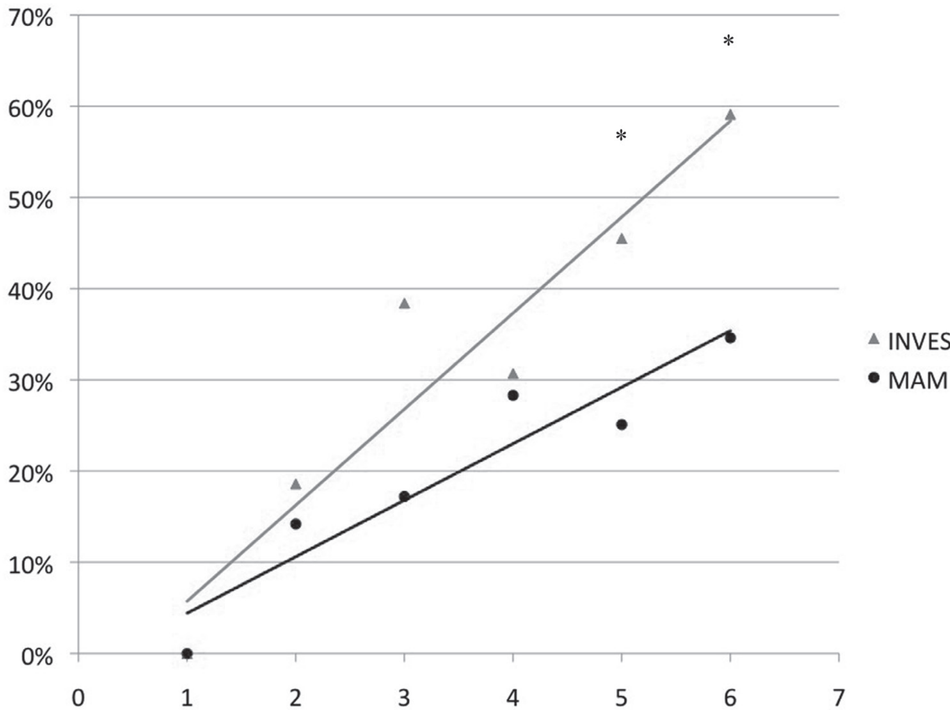


**Figure 1.** Relative improvement for the INVEST and MAM group during the curriculum. * indicates statistical significance

**Table 2.** Trainees opinion (mean) on the INVEST curriculum. Statements were evaluated on a 5-point Likert scale. 1: fully disagree, 2: disagree, 3: neutral, 4: agree, 5: fully agree.

| | INVEST | MAM | P |
|---|---|---|---|
| INVEST is fun | 4.6 | 4.2 | 0.42 |
| With INVEST I can do more | 3.8 | 3.6 | 0.91 |
| INVEST causes less supervisor interruptions | 3.8 | 3.2 | 0.32 |
| INVEST improves my learning curve | 4.6 | 4.0 | 0.17 |
| INVEST is a uniform training method | 4.8 | 4.8 | 1.00 |
| INVEST is useful after 6 times | 2.8 | 1.6 | 0.13 |
| I would like INVEST for other procedures | 4.2 | 4.2 | 0.74 |

## Conclusions and discussion

This study was conducted to explore the potential benefit and the trainee acceptance of intraoperative video-enhanced surgical procedure training for laparoscopic surgery. The INVEST curriculum significantly enhanced skill development during the early learning curve for laparoscopic cholecystectomy. Trainees indicated being positive about the content and the idea of the curriculum.

In our opinion, INVEST should not be seen as a standalone training curriculum. It should be an integrated part of a complete laparoscopic curriculum that teaches all aspects of skill-based, rule-based, and knowledge-based behavior. Therefore, a balanced training program commences with essential basic skills training on VR and/or AR simulators. Elements of procedures should be practiced in box trainers with cadaver models [25]. Ideally, trainees should attend courses that use live animal models or human cadavers to perform specific procedures on healthy organs before they go to the operating theater to perform their first procedures on real patients with INVEST.

This study did not demonstrate a significant difference in skill acquisition for three of the seven items on the OSATS global rating scale: (1) respect for tissue, (3) instrument handling, and (4) knowledge of instruments. In our opinion, respect for tissue is part of knowledge-based behavior and cannot be trained with a video. Appreciation of tissue is individually determined and comes with experience. Instrument handling cannot be trained with a video. The SIMENDO training curriculum provided the initial training in instrument handling. Further acquisition of instrument handling skills comes with experience. Knowledge of laparoscopic instruments was not part of the INVEST video and therefore we were not surprised with these results. We are exploring the possibilities of adding this skill to the video. All the other items on the OSATS scale that did significantly improve with the INVEST curriculum were part of the training video.

A possible weakness of this study is the small group size, which makes it vulnerable for type I error. While designing this study, measures were taken to minimize this risk. First, the level of surgical and laparoscopic experience among the trainees had to be very uniform on admission. None of them had noteworthy laparoscopic experience and, before randomization, each trainee was identically prepared with the SIMENDO basic laparoscopic skills curriculum. Second, we tried to score the performance of the trainees as uniformly as possible. The OSATS global rating scale is a validated tool for evaluating technical skills in a reliable and reproducible manner [18]. Data derived from the OSATS global rating scale in this study proved to be internally consistent. In addition to comparing OSATS scores between the groups after completion of the curriculum, we calculated and compared the individual improvement in skills for each trainee from the initial to the final procedure in the curriculum. When we compare improvement, each trainee has his or her own baseline and completion scores that translate into a more reliable outcome than just comparing the completion scores between the groups.

Finally, we tried to minimize bias caused by the supervising surgeon who also evaluated the procedure and filled out the OSATS global rating scale. By using three different surgeons in random order, the surgeons were not aware of a trainee's performance on previous procedures. The supervising surgeons could obviously not be blinded for the different arms of the study. Furthermore, comparing absolute and relative skill improvements instead of OSATS scores also corrected for potential bias caused by supervisors overrating trainees in the INVEST group. A possible way to avoid this observer bias would be the employment of blinded and independent surgeons who perform the assessment postoperatively by means of procedure videos. However, to our knowledge there is no validated tool for scoring surgical skills on procedure videos. For future analyses, we are exploring the possibility of scoring procedure videos by means other than OSATS.

The outcome of this study in exploring the feasibility and potential benefit of INVEST for procedure training inside the OR is very promising. Future developments within the laparoscopic cholecystectomy video will comprise the inclusion of instrument handling and knowledge of instruments, since these skills were not addressed in the present video. In addition, we are considering employing INVEST for more advanced laparoscopic procedures.

In conclusion, we recommend INVEST for procedure training inside the OR, providing a uniform, efficient, and stimulating training environment that also appreciates patient safety. INVEST supports supervising surgeons in coaching trainees in their early learning curve after the transition from skills lab to the operating theater. It improves the early learning curve, it is easy to use in daily practice, and it costs very little extra time.

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# Chapter 6

# Effective and efficient learning in the operating theater with intraoperative video-enhanced surgical procedure training

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## Abstract

*Background* INtra-operative Video Enhanced Surgical procedure Training (INVEST) is a new training method that is designed to improve the transition from basic skills training in a skills lab to procedural training in the operating theatre (OR). Traditionally, the master-apprentice model (MAM) is used for procedural training in the OR, but this model lacks uniformity and efficiency at the beginning of the learning curve. This study is designed to investigate the effectiveness and efficiency of INVEST compared to MAM.

*Methods* Ten surgical residents with no laparoscopic experience were recruited for a laparoscopic cholecystectomy training curriculum either by the MAM or with INVEST. After a uniform course in basic laparoscopic skills, each trainee performed six cholecystectomies that were digitally recorded. For 14 steps of the procedure, an observer who was blinded for the type of training determined whether the step was performed entirely by the trainee (2 points), partially by the trainee (1 point), or by the supervisor (0 points). Time measurements revealed the total procedure time, and the amount of effective procedure time during which the trainee acted as the operating surgeon. Results were compared between both groups.

*Results* Trainees in the INVEST group were awarded statistically significant more points (115.8 vs. 70.2; $p<0.001$) and performed more steps without interference of the supervisor (46.6 vs. 18.8; $p<0.001$). Total procedure time was not lengthened by INVEST while the part performed by the trainee was significantly larger (69.9% vs. 54.1%; $p=0.004$).

*Conclusion* INVEST enhances effectiveness and training efficiency for procedural training inside the OR without compromising OR time efficiency.

# Introduction

Minimally Invasive Surgery (MIS) is difficult to learn and to teach. Compared to open surgery, learning curves for mastering procedures appear to be longer. MIS confronts the operating team with ergonomic conditions and technical skills that are not employed in open surgery [1,2]. Surgeons work with long instruments that pivot on the abdominal wall. This results in inverted instrument movement inside the abdomen, limited haptic feedback, and less degrees of freedom [3]. The visual feedback of the surgeon's actions is displayed on a 2-dimensional video screen that lacks depth perception and is moved away from the patient, disturbing the natural eye-hand-target axis [2,4]. Surgeons and residents in surgery have to master these technical skills and challenges before they can perform any MIS procedure appropriately and safely [5].

Traditionally, surgery has been taught following the master-apprentice model (MAM). In this model the surgical trainee learns to perform surgical procedures under the supervision of a qualified surgeon. The supervising surgeon instructs the trainee and, when necessary, he temporarily takes over the procedure to demonstrate how a difficult step is performed.

Nowadays, work hour regulations for residents on one hand and the necessity to master more difficult MIS procedures on the other, lead to the development and validation of various training programs [6,7]. The mainstay of each of these programmes is to teach the important elements of MIS effectively and efficiently while the exposure of patients to a trainee's early learning curve is avoided [8,9]. The basic laparoscopic motor skills can be practiced repeatedly on box trainers, virtual reality (VR), and augmented reality (AR) trainers. VR trainers allow repeated practice of various exercises and record parameters such as instrument path length, collisions and time to objectively score the trainee's performance on these exercises. A disadvantage of most VR trainers is the lack of haptic feedback for instrument- and tissue handling [10]. Box trainers do provide haptic feedback, and use real laparoscopic instruments [11]. They are used to train basic laparoscopic skills but can also serve for training procedure-specific skills with cadaver organs inside the box. A disadvantage of the box trainer is the absence of an automated and objective scoring system, necessitating the presence of a qualified trainer when the box trainer is to be applied for certifying a proficient amount of skills of the trainee [6].

Animal model training and cadaver training is very helpful to practice entire procedures once the basic skills are mastered. It allows procedural training without exposing patients to the beginning of a learning curve, but it is also very resourceful and not available on demand. However the most important element in training a specific surgical procedure remains the training on a real patient with an experienced surgeon at the trainee's side. Initially the supervising surgeon will perform a large portion of the procedure to

demonstrate the sequence of steps and their important aspects. A major disadvantage of this training model is that steps can only be performed once per procedure either by the trainee or the supervising surgeon. When the supervisor takes over, that part is lost for the trainee who has to wait for the next operation to perform the step himself.
In order to minimize the frequency of intervention by the supervisor, and to maximize the operating time for the trainee, we created a new training method called: INtra-operative Video Enhanced Surgical procedure Training (INVEST). Short instruction videos demonstrate all the key elements and essential tips and tricks of the procedure. This is done step by step and on demand inside the operating room (OR).
In previous research we demonstrated that INVEST had a positive effect on the learning curve assessed on an OSATS global rating scale [12,13]. The aim of this study was to further evaluate whether this positive effect of INVEST was due to an increased effectiveness and efficiency of surgical procedure training inside the OR in comparison to the traditional master apprentice model. It was hypothesized that this type of video instructions would reduce interventions by the supervising surgeon and increase the number of steps that can be performed by the trainee during his initial experience with laparoscopic procedures.

# Methods

In a randomized trial with repeated measurements, trainees were randomly assigned to a structured curriculum to train 6 laparoscopic cholecystectomies (LC) utilizing either INVEST or the usual MAM.

## Patient selection and supervision

Sixty patients with uncomplicated symptomatic gallstone disease were selected for this study. All patients were asked to give informed consent for recording the procedure for research purposes and for the fact that a resident would perform the procedure under the supervision of a qualified surgeon. Patients were also informed about INVEST and explained that the procedure itself did not differ between the experimental- and control groups.
Three dedicated laparoscopic surgeons were also randomly assigned to supervise the procedures in both groups. They were conversant with the latest guidelines and approved the content of the instruction video. The supervising surgeons were blinded for the progression of the trainee in the curriculum of 6 cholecystectomies. The surgeons guarded the safety and the flow of the procedure, they gave verbal instructions and, when

necessary, they temporarily took over the procedure. The timing and reason for temporarily taking over the procedure was decided on the supervising surgeon's professional autonomy.

## Trainee selection

Ten trainees were included in this study. All trainees were registered residents in surgery, they were in the early phase of their training and resided at the department of surgery at Leeuwarden Medical Center. Criteria for inclusion were at least 6 months of experience in open surgical techniques and the successful completion of a training course in basic surgical skills. Exclusion criteria were any hands-on experience with LC and a cumulative experience of >5 cases in other laparoscopic procedures.

## Trainee preparation

Since the trainees had minimal previous exposure to laparoscopic techniques, they also had no practical experience with the basic motor skills that are unique to laparoscopic surgery. These skills should be mastered before anyone can be safely and efficiently trained in a specific laparoscopic procedure. Therefore, before random assignment to INVEST or MAM, all residents scheduled for this study developed their basic laparoscopic motor skills on the SIMENDO laparoscopy trainer (Simendo, Rotterdam, The Netherlands). This validated VR simulator has a variety of exercises using abstract tasks to develop hand-eye coordination and laparoscopic motor skills. Additionally, it is equipped with a proficiency-based technical skills training curriculum [14,15]. Successful completion of the SIMENDO training curriculum indicates a sufficient level of basic laparoscopic technical skills to allow safe participation in laparoscopic procedures inside the OR under the supervision of a qualified surgeon. As an additional result of this curriculum, the technical skills of all the trainees were calibrated at an equal level.

After completing the SIMENDO curriculum, residents were randomly assigned to one of the two arms of this study by drawing a sealed envelope.

In both groups, each resident performed six LCs within two weeks. Residents prepared themselves for these procedures in standard fashion using textbooks, anatomy books and online information. During the procedure itself, the control group was trained using MAM. The experimental group, in addition to being supervised by a qualified surgeon, was trained with INVEST. We controlled for equal levels of surgical skills at baseline in order to avoid differences in outcome that are due to initial differences among participants.

## Operating theatre setup

All procedures were performed in a dedicated MIS suite. This is a fully integrated OR in which laparoscopic equipment and multiple flat screen monitors are permanently installed to be operational on demand. In the INVEST-setting, two monitors were facing the operating trainee and the supervising surgeon, providing an ergonomically safe posture. One monitor displayed the operative image; the other was used for the video instruction. A third monitor displayed the operative image for the scrub nurse. The 7 video clips were presented on demand as soon as the operating team was ready for the next stage of the procedure.

The complete procedure was digitally recorded including audio channels from the trainee and the supervising surgeon. The open introduction and closure of the abdominal wall and skin were recorded with a room overview camera. The uncompressed image of a High-Definition CCD camera connected to a 30° laparoscope was recorded non-stop during the laparoscopic part of the procedure. To facilitate the post-operative video analysis, the supervising surgeon was instructed to visually mark each transition from one stage to the next by pulling the laparoscope into the trocar for a few seconds. This was also done when the role of operating surgeon changed from trainee to supervisor and vice versa.

## The INVEST instructional video

We created a step-by-step instructional video in conformity with the guidelines for LC as formulated by the Association of Surgeons of the Netherlands [16]. These guidelines are similar to the guidelines formulated by the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and the European Association for Endoscopic Surgery (EAES) with additional emphasis on the importance of the Critical View of Safety (CVS) [17]. We identified 14 separate steps in the standard LC that were selected to be included in the instructional video (Table 1). All 14 steps of the procedure that are described in the guidelines were incorporated chronologically into seven video clips. Each video clip describes a clearly identifiable stage of the procedure: 1 open introduction of the first trocar, 2 inspection and accessory trocar placement, 3 opening of peritoneal envelope, 4 creation of the CVS, 5 clipping and division of cystic duct and artery, 6 retrograde cholecystectomy, 7 gallbladder removal and closure. For each of these seven stages a 1-minute video clip was created, demonstrating anatomical landmarks, key-elements and operative techniques essential to that particular step and stage of the procedure. Video clips were displayed on demand on a second screen next to the operative screen when the trainee was ready for the next step of the procedure. For safety reasons, neither the trainee, nor the supervising surgeon was allowed to continue the procedure while the instruction video was playing. After completion of each video clip, a written summary appeared and was displayed on the accessory screen while the trainee performed the next step.

**Table 1.** Description of the 14 steps of the procedure that were included in the INVEST video clips

| INVEST video | | Step |
|---|---|---|
| 1. | 1. | Open introduction |
| 2. | 2. | Diagnostic laparoscopy |
| | 3. | Accessory trocar placement |
| 3. | 4. | Positioning of the gallbladder |
| | 5. | Incision peritoneum medially |
| | 6. | Incision peritoneum laterally |
| 4. | 7. | Dissection of cystic duct |
| | 8. | Dissection of cystic artery |
| | 9. | Identification + documentation CVS |
| 5. | 10. | Clipping + division cystic artery |
| | 11. | Clipping + division cystic duct |
| 6. | 12. | Retrograde cholecystectomy |
| 7. | 13. | Gallbladder and trocar removal |
| | 14. | Closure of abdominal wall and skin |

## Assessment

Assessment of the 60 procedures was performed by one observer after the procedures were randomly numbered. The observer was blinded for whether the LC was performed in the INVEST of MAM curriculum and for the order of the 6 procedures in the training curriculum. To blind the analysis of the recorded procedures, the segments that were recorded while the INVEST video was displayed and the actual operation was on hold, were cut. However, the duration of these deleted segments were included in the time measurements.

## Effectiveness

The effectiveness of procedural training can be described by the relation between the possible amount of training opportunities in a procedure and the amount of training that was actually realized.
Effectiveness of the INVEST and the MAM training curriculum was estimated by measuring the amount of active participation of the trainees across 6 LCs. The blinded observer determined for each of the 14 separate steps of the LC whether it was performed entirely by the trainee (2 points), partially by the trainee (1 point) or by the supervisor (0 points).

Consequently, for each procedure, trainees could receive a score between 0 and 28 points. The amount of steps performed by the trainee, the individual scores per procedure and the summed scores of the 6 procedures within the curriculum were calculated and compared between the INVEST and MAM training method in order to visualize the longitudinal score development as well as the overall effect of the curriculum.

## Efficiency

The efficiency of a training method can be described by the relation between amount of training given to the trainee and the amount of OR time that was consumed for these purposes. We determined this relation in several ways.

In the first place we measured OR time efficiency. With the procedural videos we measured the total procedure time (TPT) and the amount of time in which the trainee acted as the operating surgeon, the so-called 'effective procedure time' (EPT). OR time efficiency was assessed as the ratio between EPT and TPT, which expressed the relative amount of operating time that was consumed by the trainee without supervisor intervention.

In the second place we investigated the efficiency of the training method itself. To determine the operating pace of a trainee (OPT), we calculated the relation between the EPT used by the trainee and the amount of points earned while he was operating. Finally, we determined for the INVEST and MAM training method how much OR time (TPT) had to be spent to allow the trainee to earn a point (TPTpoint) or to participate in a step (TPTstep).

## Statistical analysis

Due to the small sample size and to the risk of chance capitalization by multiple testing, we did not analyse longitudinal effects within both training groups. Although each variable that was used in the analysis was normally distributed (Shapiro Wilk test, $p > 0.05$), the Wilcoxon-Mann-Whitney test for independent samples was conducted to evaluate the hypothesis that trainees assigned to the INVEST group would perform better, on the average, than those assigned to the MAM group. Statistical significance was set at $p < 0.05$. Effect Sizes were calculated only for statistically significant differences, as it makes no sense to estimate clinical relevance of a result that may be based on random variation. Cohen's effect size (ES) for independent samples was used to estimate the magnitude of these differences [18]. According to Cohen's thresholds an ES < 0.20 indicates a trivial difference, 0.20 to 0.50 a small difference, 0.50 to 0.80 a moderate difference and > 0.80, a large difference.

## Results

Ten trainees were randomly assigned to the two arms of the study without dropout after inclusion. Each trainee completed the basic skills training curriculum on the SIMENDO successfully to the preset level of proficiency before randomization. There were no significant differences in training time to acquire the proficiency level between both groups. Each resident performed 6 laparoscopic cholecystectomies within the set period of two weeks and all the procedures were successfully recorded. There were no technical problems with displaying the instruction video in the INVEST group.

### Effectiveness

Each LC was assessed on 14 steps with a maximum achievable score of 28 points per procedure if all steps were entirely performed by the trainee. Therefore, the curriculum of 6 LCs contained 84 steps with a maximum achievable score of 168 points. In the analysis of the individual procedures, the trainees trained with INVEST were granted significantly higher scores for procedure 1,3,5 and 6. Procedures 2 and 4 did not show statistically significant differences (Figure 1).

The medians of summed scores across 6 procedures were 117 and 65 points in the INVEST and MAM group respectively and were statistically significant higher among INVEST trainees. The mean ranks of INVEST and MAM were 8.0 and 3.0 respectively; W=15, Z=-2.61, p<0.05. (Table 2a) Analysis of the 84 steps indicated that in the MAM group, significantly more steps were only partially performed by the trainee (1 point) or were performed by the supervisor (0 points). The median of steps that were entirely performed by the trainee was higher among INVEST trainees (49 vs. 17;W =15. Z=-2,63,p<0.05). Differences between both training models were large with effect Sizes > 0.80 (Table 2a).

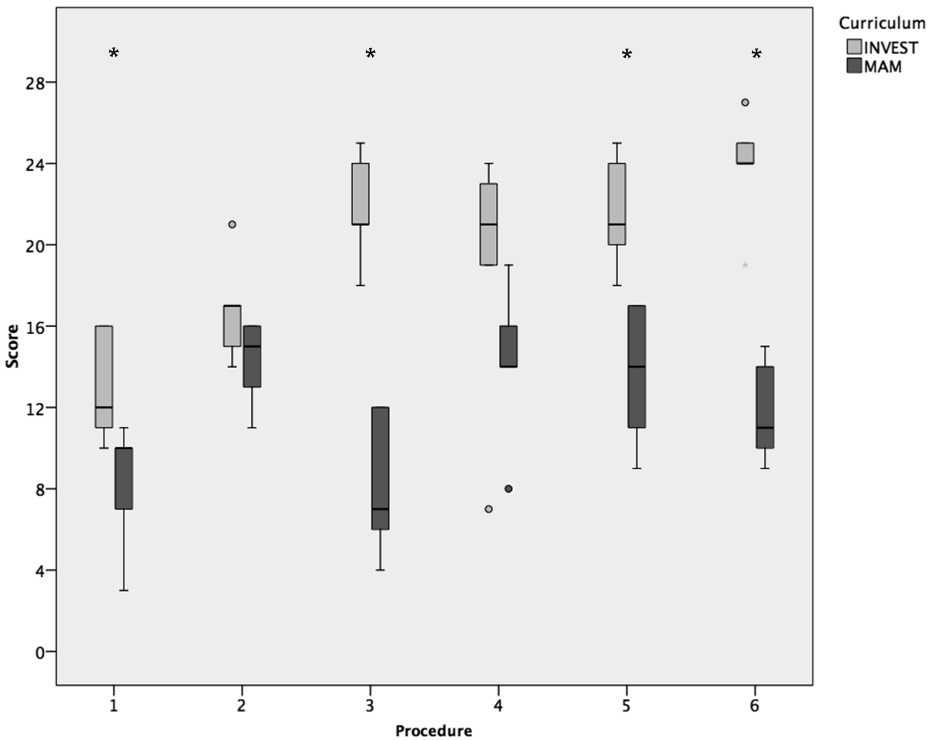


**Figure 1.** Boxplot presenting the scores (min 0, max 28 points) per procedure as achieved by the trainees in the INVEST and MAM groups. * indicates statistical significant difference.

**Table 2a.** Differences between the INVEST and MAM group on overall performance across all steps and the cumulative number of times trainees scored 0 points, 1 point or 2 points

| | INVEST Median | MAM Median | Z-value | *P* | ES |
|---|---|---|---|---|---|
| Total performance score | 117 | 65 | 2.61 | 0.01 | 4.05 |
| Performance | | | | | |
| 0 point (entirely performed by supervisor) | 16 | 31 | 2.62 | 0.01 | 2.95 |
| 1 point (partially performed by trainee) | 22 | 36 | 2.31 | 0.02 | 2.26 |
| 2 points (entirely performed by trainee) | 49 | 17 | 2.61 | 0.01 | 4.31 |

**Table 2b.** Efficiency for the INVEST and MAM group.

| | INVEST Median | MAM Median | Z-value | *P* | ES |
|---|---|---|---|---|---|
| TPT (min) | 412 | 453 | 0.94 | 0.34 | NS |
| EPT (min) | 279 | 239 | 1.98 | 0.04 | 0.59 |
| Ratio EPT/TPT (%) | 70.54 | 52.57 | 2.61 | 0.01 | 2.57 |
| OPT (EPT/point) | 2.43 | 3.41 | 2.40 | 0.02 | 2.00 |
| TPTstep (min) | 5.94 | 8.16 | 2.61 | 0.01 | 3.36 |
| TPTpoint (min) | 3.45 | 5.94 | 2.61 | 0.01 | 3.33 |

Items are total procedure time (TPT), Effective procedure time during which the trainee was operating (EPT) and the ratio between these EPT and TPT. The operating pace of the trainee (OPT) indicated the EPT needed per point scored. The overall efficiency in TPT needed to let a trainee participate in a step (TPTstep) and the TPT needed to let the trainee score a point (TPTpoint).

### Efficiency

The time measurements to compare OR time efficiency between both groups showed no statistical significant difference for TPT. The procedure time that was available for the trainees (EPT) was significantly longer in the INVEST curriculum. Moreover, when calculating the relative amount of operating time, the trainees in the INVEST group performed a significantly larger part of the procedure than trainees in the MAM group (Table 2b). Analysis of the efficiency of the training method revealed that, while acting as operating surgeon, the trainees in the INVEST group performed at a faster operating pace. They were able to perform more steps of the procedure, and scored more points per minute, expressed in OPT. The overall efficiency calculations indicated that the INVEST curriculum required less TPT to allow the trainee to score a point, resulting in a lower TPTpoint. Similarly, it required less TPT to allow a trainee to participate in the partial or complete performance of a step of the procedure, resulting in a significantly lower TPTstep in the INVEST curriculum (Table 2b).

## Conclusions and Discussion

Intra-operative video enhanced surgical procedure training (INVEST) is a new concept for procedural training inside the operating theater. With this study we confirm that, when compared to the traditional Master-Apprentice-Model, INVEST can create a more effective and efficient learning environment for surgical residents in the early phase of their learning curve for the laparoscopic cholecystectomy.

Effectiveness of the training curriculum is significantly enhanced. The INVEST video clips demonstrate the procedure step-by-step and on demand inside the OR. Immediately after watching the instruction, the trainee applies the instructed material in practice. As a result of this, out of the 84 available steps in the curruculum, trainees in the INVEST group could participate as operating surgeon in 71 steps (82%). They performed 49 (55%) of these steps without interference of the supervising surgeon and only 16 (18%) of the steps were completely performed by the supervising surgeon. The procedures performed with INVEST were granted more points throughout the curriculum (Figure 1). Although we did not relate the effectiveness of a curriculum to a possible learning curve, there is an obvious trend, indicating that the amount of points that were scored increased per procedure in the curriculum. In procedure 6, trainees in the INVEST group are the operating surgeon during 86% of the procedure time during which they are awarded 85% of the available points (Figure 1).

Efficiency is important for both the workflow inside the OR and the learning curve of the trainee who is bound to the increasing working hour restrictions. Our time measurements demonstrate that INVEST does not compromise OR efficiency, making it suitable for training in daily practice. A trainee can watch the instruction videos and perform the role of operating surgeon during a significantly larger part of the procedure without lengthening of the total procedure time. Although we cannot conclude anything about the overall result of this curriculum on the learning curve, this study shows that INVEST can increase the part of the procedure used for training by 18% (Table 2b). Within the trainee's operating time, INVEST allows him to be involved in a significantly larger amount of steps, that can be performed by the trainee at a faster pace. Therefore, the total amount of OR time that has to be invested to allow a trainee to perform a step or to be awarded a point is substantially reduced.

Procedural training inside the OR is an essential part of the education for young surgeons. Modern skills labs can be used for safe and repetitive training of elementary laparoscopic motor skills and for the first steps of procedural training. During this early phase of a learning curve, the trainee learns the basic skills necessary to safely perform laparoscopic surgery. However, after the acquisition of these basic skills, the trainee has to learn procedural skills and problem-solving skills by participating in surgical procedures at the side of an experienced supervising surgeon. INVEST contributes to the efficiency and effectiveness of this learning process in a number of ways. By presenting a stepwise instruction video inside the OR, the trainee receives the instruction at the moment it is needed. Immediately after watching the instruction video, the trainee applies the knowledge to perform the next part of the procedure. Therefore the trainee both sees and performs the operation within one procedure. Whether this setup of intra operative, stepwise and on demand presentation enhances the retention of the demonstrated skills

compared to watching the instruction video's before the procedure is likely, but not proven and will be subject of further studies.
An additional effect of INVEST is that it provides a very uniform method of procedural training that complies to the national and international guidelines. Also the supervising surgeon sees the instruction video. Since he knows what step the trainee will perform next and with which strategy, it is likely that the supervising surgeon is more confident in allowing the trainee to perform the procedure.

In a previous study we demonstrated that surgical residents trained with INVEST had a significantly faster improvement of skills than a similar group of residents trainees with the Master-Apprentice-Model [12]. In that study we used the validated global rating scale of the Objective Structures Assessment of Technical Skills (OSATS) [13]. The INVEST group experienced a significantly faster improvement of skills on the OSATS global rating scale. The longitudinal improvement on the OSATS global rating scales had a very similar development as the awarded points for the procedures in this study that are presented in Figure 1. This emphasizes the fact that surgical skills develop with practice. The more a surgical trainee is exposed to practicing a technical or procedural skill, the faster the skill is mastered. INVEST does not only allow the surgical trainee to perform procedural skills more frequently, but all the involved procedural skills are also repetitively demonstrated to the trainee immediately before performing these skills.
A weakness of this study is the small group size, which makes the outcome vulnerable for type I error. In the study design confounding factors were controlled in the following ways: First, the level of surgical and laparoscopic experience among the trainees was very uniform on admission. None of them had noteworthy laparoscopic experience and, before randomization, each trainee was identically prepared with the SIMENDO basic laparoscopic skills curriculum. Second, trainees were randomly assigned to either group to control for the influence of individual differences. Third, appraisal of the recorded procedures was performed by an independent observer in random order and blinded for INVEST or MAM, for the name of the trainee and for the number of procedures that the trainee had performed.

Another important aspect of procedural training is the safety of the patient. With the intra operative video's we introduced a potential distraction into the OR. To reassure that there was always a clear view of the operating field, we used a dual flat screen setup, one screen displaying the live image from the endoscope held by the supervising surgeon, the other displaying the instruction video for the trainee. While playing the instruction video for the trainee, the supervising surgeon was instructed to watch the patient.

In order to further explore the potential benefit of INVEST we are planning to start a multicenter study that investigates the effect of INVEST among a larger group and for different procedures. We are interested in the long-term benefits of INVEST and the potential shortening of the learning curve to master a procedure. The Dutch surgical resident training program is becoming more and more competency based. Once a skill or procedure is mastered, the trainee can start to train the next procedure. Uniform, effective, and efficient skills training as well as uniform evaluation of acquired skills that can be transferred from one teaching hospital to the other are very important issues of modern surgical resident training.

In conclusion, we like to recommend INVEST for procedural training inside the OR, providing a uniform, efficient, effective and stimulating training environment that also appreciates patient safety. Compared to the traditional Master-Apprentice Model, INVEST enables surgical trainees to perform a substantially larger part of the procedure with less interference of the supervising surgeon. OR efficiency is not compromised by INVEST.

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# Chapter 7

# General discussion and future perspectives

# General discussion and future perspectives

Minimally Invasive Surgery (MIS) and laparoscopic surgery in particular, has undergone an enormous development in the past two decades, making modern laparoscopic surgery a technique with obvious patient related benefits. Furthermore, large, well-designed studies demonstrate that the clinical, oncologic, and functional outcome of the laparoscopic approach is at least of equivalent quality as the comparable open approach [1,2]. It is to be expected that MIS will be the preferred technique for more and more surgical indications, making the topics ergonomics, efficiency and training in MIS actual and of ongoing importance. As a result, many surgeons want to embrace MIS in their practice. In order to achieve this, trainee surgeons have to be trained in a proficient, efficient and uniform way. Furthermore, the long-term consequences of the static and upright, non-ergonomic posture of the laparoscopic surgeon and his operating team is not very well known. Finally, the efficiency of the process in the operating theater (OR) can, and has to be improved by further development of dedicated MIS suites.

## Part I: Ergonomics and Efficiency in Minimally Invasive Surgery

The ergonomic interaction between the surgeon and his working environment is dependent on several factors. Amongst these, the relation between the monitor position and the posture of trunk and neck of the operating team is an important factor and is addressed in this thesis. For this factor we demonstrated that an ergonomically save neck posture can be realized in the MIS suite and that this posture has a positive effect on the amount of perceived physical stress during the procedure.

After the promising results of this research, we looked for means to perform continuous, reliable, intra-operative posture analysis of the entire spine. After extensive evaluation of the possible techniques to do this, we experimented with electromagnetic (EM) motion sensors. Other motion analysis systems, such as infrared cameras that record motion of objects by means of reflectors that are attached to the object, were not suitable for measurements in the crowded and sterile environment inside an OR.(unpublished data)

The EM motion analysis system is composed of a transmitter with multiple receiver sensors. The transmitter's high frequency signals reach the sensors that are attached to the surgeon's body at different intervals and angles. These measurements are then used to calculate both the position of each sensor in the 3-dimensional space as X, Y, and Z coordinates and the orientation of the sensor in the horizontal plane (rotation/yaw), the sagittal plane (flexion/pitch) and the coronal plane (lateroflexion/roll). EM signals protrude clothing and therefore the sensors could be worn underneath a sterile gown. For analysis of the spine, we experimented with three sensors: the first attached to a head band, the second was taped onto the skin at the level of spinous process T1, and the third was taped onto the skin at the level of S1. After calibration of the sensors with the subject standing in a neutral posture, 3 dimensional postural changes of the neck and thoracolumbar spine could be monitored during the procedure. However, measurements in a crowded OR turned out to be unreliable due to interference of other devices emitting EM signals such as electrocautery and due to reflection and distortion of the EM pulses on nearby metal objects, concrete ceiling, walls, and floor.(unpublished data)

In the near future, further progression can be achieved in posture and movement analysis due to new developments that originate from the gaming and Smartphone industry. In the iPhone 4 mobile digital device, for example, a 3-axis gyroscope in combination with an accelerometer provides very accurate 3 dimensional motion analysis [3]. Applying these techniques for ergonomic posture analysis enables live monitoring without the use of an EM transmitter or an infrared camera. Sensors can be worn underneath a surgical gown and information can be transmitted to a laptop computer via Bluetooth without interference, making them suitable and save for use inside an OR. This way the quality of posture and motion of the OR team during live MIS can be investigated and, by adding simultaneous EMG registration of the associated muscles of trunk and neck, a true ergonomic profile can be made and used for future improvements in the design of the MIS suite.

Substantial ergonomic improvements can be achieved when the physical working environment of the surgeon can be moved away from the sterile field around the patient. The posture and motions of surgeons during laparoscopic procedures is predominantly determined by two factors: in the first place by the set of movements required for instrument manipulation within the operating field and in the second place by the postural adaptations needed to position himself at the operating table in order to be able to perform the surgical procedure adequately. With robot assisted endoscopic surgery, a form of telemanipulation, these two factors can be separated and further optimized [4,5]. In robot assisted endoscopic surgery, the surgeon performs the procedure outside the sterile environment on an ergonomically designed console. Comfortably sitting at the console, the surgeon remotely operates a robot that executes the surgeon’s manipulations within the sterile operative field.

Additionally, robot assisted endoscopic surgery can overcome some of the other challenges of MIS. Inside the console, the natural working axis is restored, by re-aligning the surgeon’s visual axis with his hands, the instruments and the target organ, improving the surgeon’s dexterity. Furthermore, a laparoscope with two separate optical channels is used to provide individual images for each eye with which a 3-dimensonal perception of the operative field can be created inside the console.

With respect to instrument manipulation, the robotic instruments are equipped with two extra degrees of freedom when compared to conventional laparoscopic instruments, restoring the 'wrist' function during manipulation. Additionally, the console compensates for inverted movements and scaling effect of the laparoscopic instruments that is caused by their pivot on the abdominal wall. All these ergonomic improvements reduce the surgeon's physical and mental exertion during a procedure, allowing him to perform complex tasks in a more precise and comfortable way.

Efficiency of the operative and perioperative process can be further optimized. In this thesis the advantage of the MIS suite was demonstrated in preparing and cleaning up for a minimally invasive surgical procedure. Due to work performed by other disciplines that are present in the OR, the measured advantages did not result into a reduction of turnover time between two procedures. To achieve this, the entire work process within the interoperative period has to be analyzed, and, where applicable, optimized. Other studies indicate that the inter-operative time can be reduced considerably following specific team training [6].

Also the intraoperative efficiency can be increased by new techniques that are present in an MIS suite. All equipment is permanently installed and can be remotely operated from a central console. The OR nurse that has to operate the equipment can do this more efficiently and can keep a safe distance from the sterile operative field.

A different approach is to control the equipment by the surgeon by means of voice control or by a sterile touch pad within his reach. The advantage is that the surgeon does not have to give the command to the circulating OR nurse and that the equipment is adjusted immediately when he needs it and exactly at his preferences. A potential drawback might be that this control system causes distraction by the necessity for the surgeon to look away from the operative field.

Another interesting future development is the automated control of the laparoscope with eye tracking. In current practice, a scrub nurse or an assisting surgeon holds the laparoscope to visualize the operative field and the surgeon's actions. Many times per procedure, the surgeon has to verbally or manually adjust the view provided by the 'cameraman' to his preferences. Eye tracking is the technique that registers which part of the screen a person is focusing on. When an eye tracking system is paired to an already existing automated camera holder, the surgeon's area of interest is always focused and in the center of the screen.

MIS requires many hoses and cables that run from the sterile field to the peripherals supplying illumination, insufflation, suction, electricity, etc. Efficiency can be further improved when some of these connections can be omitted because of wireless equipment. Experiments with wireless camera's are in full swing and the first wireless harmonic scissors are recently presented to the public.

In our opinion, the MIS suite of the future is a modular system that can be designed to one's specific needs. Different modules for robot assisted endoscopic surgery, endoscopy,

natural orifice transluminal endoscopic surgery (NOTES), interventional radiology, and other modalities can be incorporated.
Teleconsultation and teleproctoring is a different form of efficiency. Teleconsultation in MIS can be defined as the process of accessing remote information to aid the operative process [7]. Teleconsultation can be divided into four categories: 1. Non-live teleconsultation: accessing a medical website or the patient's digital files or radiology archive. 2. Live teleconsultation without video: By wearing a headset, the surgeon can consult a colleague who is outside the OR. 3. Live teleconsultation with one-way video: From the OR an audiovisual connection can be made with a workstation. The person at the workstation can watch the procedure and communicate with the surgeon. 4. Live teleconsultation with 2-way video. Basically the same as 3, only with the addition that the person behind the workstation can edit the video, draw in an image and send it back to the OR. Live teleconsultation as presented in category 3 and 4 are also known as teleproctoring. Teleproctoring allows an expert to supervise one or multiple procedures from his workstation in his own hospital or office without the need to be physically present inside the OR. This is an interesting and efficient tool in an era of increasingly stringent quality standards in healthcare that ensures expert quality of care and might be a different form of centralization and education in healthcare.

## Part II: Procedural training in Minimally Invasive Surgery

The topic of Training in MIS is currently under a lot of attention in the media and amongst the health professionals themselves. The majority of the published studies, however, are designed to demonstrate the use of a single simulator or to discuss a training method for a single procedure. Despite the positive outcomes, the disadvantage of this approach is that only a limited set of skills will be trained to a particular endpoint. This endpoint is often not the end of the learning curve and is usually accomplished in a skills lab. INVEST originated from the idea to create a safe, uniform, efficient and procedure-specific training program for the complete learning curve from basic skills training up to certification. To achieve this goal, a MIS curriculum is currently under development. In this curriculum, the three different types of behavior, as described by Rasmussen, with increasing complexity are distinguished and separately trained: Skill based behavior (basis motor skills), Rule based behavior (procedure specific knowledge and skills), and Knowledge based behavior (problem solving skills) [8]. The trainee surgeons commence their MIS curriculum with basic skills training, preferably on a simulator with a validated training program to reach a set level of proficiency. Following this step, the trainees attend a fundamental MIS course, in which basic laparoscopic techniques, skills and knowledge on equipment and instruments are educated, practiced and tested (Figure 1).

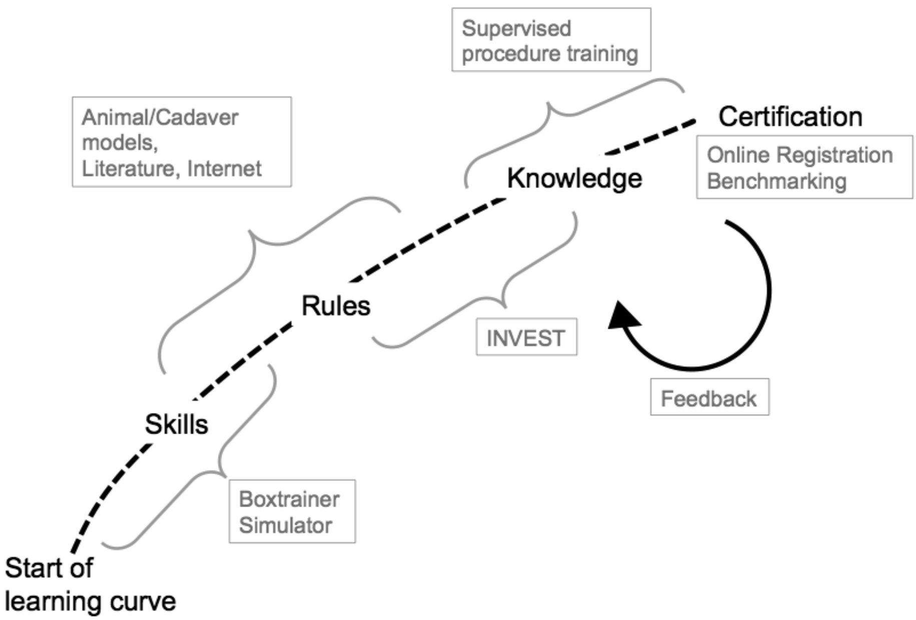


**Figure 1.** Learning curve and accompanying training methods of a random laparoscopic procedure within the MIS curriculum.

Having mastered the basic skills and knowledge (Skill based behavior), the residents can enroll in procedural training programs with increasing complexity. Each training program starts with a preliminary course in a skills lab. During the course, anatomy, physiology and pathology of the organ in question are discussed and the key steps of the associated laparoscopic procedures are taught and trained on animal models or on human cadavers (Rule based behavior). During this course, the INVEST instruction video's will be used to demonstrate the key steps while the trainees perform them in the skills lab. After successful completion of the course, the trainee continues the procedural training of the specific procedure in the OR in his own hospital, while being trained with the INVEST video's and supervised by an experienced instructor. After several procedures, the INVEST video can be left out while the trainee continues to perform procedures under supervision to refine his technique, to identify anatomical variations, and to recognize, avoid and solve potentially hazardous situations. (Knowledge based behavior) Training is continued until the trainee is certified to perform the procedure without supervision. These steps apply to each type of laparoscopic procedure. Ideally the training results are registered in a web-based portfolio and can be compared with 'bench mark data' for feedback and adjustments if needed.

There are some unanswered questions on this training curriculum and on INVEST, and these will be subject of future research projects. For each procedural training course, an INVEST video has to be developed that has content approval of all the participating hospitals and individual surgeons. Within our surgical training region we are using the Delphi method to reach consensus on all the key steps in a particular procedure that have to be included in the INVEST video and the training courses [9].

Furthermore, research is done to create a suitable assessment tool for each MIS procedure that can be used for feedback during the learning curve and for certifying the trainee at the end. Currently the Objective Structured Assessment of Technical Skills (OSATS) global rating scale is used, but this assessment has some drawbacks [10]. The OSATS global rating scale is designed to rate technical skills in a subjective fashion. During basic skills training, there is a need for objective measures that express acquisition of skills such as task completion time, instrument path length, instrument collisions and tissue damage. All these measures are objectively graded on a simulator. In a box trainer a TrEndo, a device measuring instrument movements, can be used to measure objective results such as task completion time and path length [11].

For procedural training during the second phase of the learning curve, an OSATS global rating scale is not very distinctive since it is not procedure-specific and does not assess the important aspects of rule based and knowledge based behavior. Especially these types of skills are important to assess at the end of the learning curve. Blinded assessment of key steps on the basis of recorded procedural video's using a procedure specific rating scale appears to be a promising, but possibly labor intensive solution. However, this instrument, approved by every instructor surgeon in the region, enables easy transfers of trainees between hospitals without the need for re-certification in the next hospital. Furthermore, a procedure specific assessment tool can also be used for certification and registration for already graduated surgeons.

This thesis demonstrates that aspects of minimally invasive surgery concerning ergonomics, efficiency and training pose challenges for the health professionals that practice this form of surgery. By applying ergonomic guidelines and by creating a working environment that facilitates all the special needs of MIS, and by training and certifying the present and future surgeons in a uniform, efficient and safe manner, most of these challenges can be overcome. This way minimally invasive surgery becomes advantageous for both a large group of patients and healthcare professionals.

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# Chapter 8

# Summary

# Summary

Since the first modern laparoscopic surgical procedures were performed in the late nineteen eighties, minimally invasive surgery (MIS) has developed to be the preferred operative technique for an ever growing number of surgical indications. Implementing MIS into surgical practice reduced perioperative morbidity for many interventions, and extended the indications for certain types of intervention. Furthermore, well-informed patients often prefer MIS to conventional techniques because of the superior cosmetic result. Clinics, offering a wide range of MIS, enjoy attention in the media, at the health insurance companies and in society.
Besides advantages, MIS is also associated with a number of challenges for its providers. The ergonomic quality, the efficiency, and sometimes the safety of the operative process is jeopardized by the presence of additional equipment and the need for visualization of the surgical area on a monitor. Because of this, surgeons and other specialists performing MIS, have to be trained in these techniques. Training facilities for technical and procedural skills training can and should be structured and widely available, ensuring completion of the first part of the learning curve in a skills lab and the second part in a clinical setting.

**Chapter 1** includes a brief general introduction in MIS and describes the content and context of this thesis. It also provides a brief overview of the following chapters.

After Chapter 1, this thesis consists of two separate parts.

**Part I** (chapters 2,3,4) discusses ergonomics and efficiency-related aspects of minimally invasive surgery

**Chapter 2** provides a structured overview of the existing literature in the field of applied ergonomics and laparoscopic surgery on the relation between monitor positioning and the working process. Both productivity aspects such as effectiveness (optimal result) and efficiency (minimal time investment) as well as aspects of comfort and safety during the working process were evaluated in order to provide a guideline regarding the ideal monitor position during laparoscopic surgery.
Disruption of the eye-hand-target axis occurs due to the limited freedom in monitor positioning around the operative field and is considered an important ergonomic restriction during laparoscopic surgery. The realignment of this eye-hand-target axis improves the effectiveness and the efficiency of the surgeon’s actions on one hand and it improves the ergonomic comfort and safety aspects of the surgeon’s posture during the

surgery on the other. For the operating surgeon, the effectiveness and efficiency factors on the ergonomic balance are more important than for other members of the OR team. Since the assisting surgeon and the scrub nurse perform far less laparoscopic manipulations, the comfort and safety factors are more important on their ergonomic balance. In the horizontal plane, axial rotation of the spine is prevented by a monitor position directly in front of the members of the OR team and in line with the direction in which they work. In the sagittal plane, the operating surgeon works most effectively with the monitor well below eye level and close to his operative field. The posture of the assisting surgeon and scrub nurse is comfortable when the monitor is placed just below eye level, preventing extension of the neck.

**Chapter 3.** In this chapter, the insights and guidelines that are described in chapter 2 are put into practice by means of a posture analysis of head and neck during laparoscopic cholecystectomy. The ergonomic situation in a general operating theater is compared with the situation in a dedicated MIS suite. For 16 different operating teams, each consisting of a surgeon, an assisting surgeon and a scrub nurse, neck flexion and rotation were analyzed on both types of OR. Additionally, each participant filled out a questionnaire to assess the ergonomic situation during the procedure in each type of OR. In the MIS suite, the ergonomic working environment is optimized for the entire surgical team. The posture of the operating surgeon is significantly better in the sagittal plane (flexion of the neck) and in the horizontal plane (rotation of the neck). For the assisting surgeon, a reduction in neck rotation of more than 29° to ergonomically acceptable values is realized. Values for neck flexion are similar and ergonomically acceptable in both types of OR. For the scrub nurse neck extension is significantly reduced in the MIS suite towards an ergonomically neutral posture. In the questionnaire, all members of the operative team scored the ergonomic quality of their posture significantly higher when working in the MIS suite. They also indicated to experience less posture-related physical discomfort when working in the MIS suite, where their postures were within ergonomically safe margins as formulated in chapter 2.

**Chapter 4** focuses on the efficiency of the operative process. Laparoscopic surgery requires the use of a variety of equipment that is not routinely used during open surgery. Therefore, this equipment is not permanently installed inside the OR. When laparoscopic procedures are performed in a conventional OR, this equipment has to be collected from its storage facility, and installed inside the OR. After surgery, the equipment has to be disassembled and stored again. This process is time consuming and increases the risk of damage to the equipment, connection problems and malfunctioning. In a MIS suite, all necessary equipment is permanently installed and ready for use inside the OR. The aim of the study in chapter 4 is to assess the efficiency of the perioperative process for laparoscopic procedures performed in the conventional OR and the MIS suite. Setup and disassembly times amongst three experienced surgical OR-teams were measured for a laparoscopic cholecystectomy (LC) and a laparoscopic sigmoidectomy (LS) in an experimental setting on both types of OR. Furthermore, these experimental results were compared with the workflow efficiency in daily practice. In the experimental setting, MIS suite setup and disassembly times for LC and LS were 2:41 min (39%, $p < 0.001$) and 10:47 min (68%, $p < 0.001$) shorter than in the conventional OR. In daily practice, these differences were also measured for the workflow of the surgical team, but did not result in a significantly shorter turnover time due to the workflow of the other disciplines that are present in the OR.

**Part II** of this thesis focuses on methods and effects of laparoscopic procedural training for surgical trainees. Traditionally, residents in the surgical specialties are trained according the master-apprentice model. In this model, the master surgeon repeatedly demonstrates the essential steps of a surgical procedure while the apprentice surgical trainee is gradually allowed to perform parts of the procedure under the master's supervision. This method is not very uniform and efficient. Once the master uses a part of the procedure for demonstration, the trainee cannot practice that same part of the procedure. In order to organize procedural training more uniformly and more efficiently, we have developed a new training method called INtraoperative Video-Enhanced Surgical procedure Training (INVEST).

**Chapter 5.** In this chapter we investigate the effect of the INVEST curriculum on the learning curve of a cohort of trainee surgeons. An INVEST instructional video was created for the laparoscopic cholecystectomy (lap choly) according to current guidelines. In 7 video clips, each containing a clearly identifiable part of the lap choly, the individual steps of the procedure are demonstrated and anatomical landmarks, procedural skills and potential hazards are explained.
Prior to randomization between procedural training in the OR with INVEST or procedural training according the master-apprentice model, laparoscopic basic skills were trained in the skills lab. On the SIMENDO laparoscopy trainer (SIMENDO, Rotterdam, The Netherlands) all participants practiced until they had reached a predefined and proficient level of technical skills. After randomization, participants in both groups performed 6 lap choly's that were evaluated by the supervising surgeon using an OSATS global rating scale (Objective Structured Assessment of Technical Skills). The learning effect of the curriculum was estimated by the improvement in the OSATS score during the curriculum. Furthermore, a questionnaire evaluated the participants' opinions on the INVEST curriculum.

In the INVEST group, participants achieved significantly greater increases in OSATS score than in the master-apprentice group (32.6 vs. 16.4 points, p = 0.02). Relative increase in score from the initial procedure towards the maximum possible score was 59% and 35% respectively. In the questionnaire, the participants indicated that they considered INVEST an attractive learning method, that it had a positive effect on their learning curve, and that is was considered a uniform teaching method. They would also like to use INVEST for other MIS procedures. Furthermore, they indicated that INVEST allowed the trainees to perform more steps of the operation and that intervention by the supervisor was needed less frequently. This study demonstrated that INVEST has a positive effect on the completion of the early learning curve for surgical procedural training inside the operating room. The learning effect for each operation is significantly higher than in the master-apprentice model. What this study did not demonstrate is how INVEST achieved this positive contribution.

In **Chapter 6** this issue is further analyzed. Using audio-visual recordings of each procedure performed by the cohort of trainees in Chapter 5, a time and task analysis was carried out. This analysis compared the effect of INVEST on the available operating time for the trainees and the effect on the number of steps that the trainees could perform. On the basis of these data could be determined whether the positive contribution of INVEST on the learning curve is achieved through improved efficiency (The student can operate longer per procedure), through improved effectiveness (The student can operate more steps per procedure), or by a combination of both.
In a standard lap choly, 14 steps were identified. A reviewer, using the video recordings, determined whether each step was performed by the trainee completely (2 points), partially (1 point), or not at all (0 points). In addition, the video recordings were used to perform time measurements to determine how long each procedure lasted, and which part of the procedure was performed by the trainee and by the supervising surgeon respectively. Results were compared between the trainees in the INVEST group and the master-apprentice group for 6 consecutive lap choly's.
In the INVEST group, trainees achieved a mean summed score of 116 points over 6 lap choly's (max 168 points) compared to 70 points in the master-apprentice group (p = 0.009). Furthermore, out of the 6x14 = 84 available steps to perform, the INVEST trainees were able to perform more steps completely without intervention of the supervising surgeon: 46.6 vs. 18.8, p = 0.009. The overall procedure time was similar in both groups. The percentage of operating time available for the trainee was significantly higher in the INVEST group (69.6% vs. 54.1%, p = 0.009). During the procedure in which the trainee acted as operating surgeon, the trainees were operating at a significantly faster pace in the INVEST group. (2.42 min / point vs. 3.32 min / point, p = 0.016). Because of this, the investment of costly OR time required to allow a trainee to perform a procedural step or

to earn a point was significantly less for procedural training according the INVEST method: 5.84 min / step vs. 8.04 min / step, respectively and 3.51 min / point vs. 6.14 min / point. These data substantiated the results obtained in Chapter 5 and suggested that INVEST has a positive contribution to the early learning curve for procedural training both by increased efficiency and increased effectiveness.

# Chapter 9

# Samenvatting

# Samenvatting

Sinds de eerste moderne laparoscopische ingrepen eind jaren tachtig heeft de minimaal invasieve chirurgie (MIS) in 25 jaar tijd een enorme ontwikkeling doorgemaakt en is nu de behandeling van voorkeur geworden voor een nog steeds groeiend aantal chirurgische indicaties. Door implementatie van de MIS is voor een aantal indicaties een reductie in perioperatieve morbiditeit aangetoond en kunnen indicaties voor bepaalde ingrepen verruimd worden. Daarnaast verkiest de patiënt MIS vaak boven conventionele chirurgie mede vanwege het cosmetisch resultaat. Bovendien genieten klinieken met een groot aanbod aan MIS al dan niet terecht aandacht in de media, bij de zorgverzekeraars en in de maatschappij.
Naast voordelen gaat MIS ook met een aantal uitdagingen gepaard. De ergonomische kwaliteit, efficiëntie en soms de veiligheid van het operatieproces komt in het gedrang door de aanwezigheid van additionele apparatuur en de noodzaak het operatiegebied op een monitor te moeten bekijken. Daarnaast moeten chirurgen en andere endoscopisch opererende medisch specialisten worden opgeleid in deze operatietechniek. Het trainen van technische en procedurele vaardigheden kan en moet gestructureerd en breed beschikbaar zijn, waarbij een eerste deel van de leercurve in een skillslab en het tweede deel klinisch kan worden doorlopen.

**Hoofdstuk 1** betreft een korte algemene introductie in de MIS en omkadert de inhoud en samenhang van dit proefschrift. Ook wordt er een kort overzicht gegeven van de hierop volgende hoofdstukken.

Na hoofdstuk 1 bestaat dit proefschrift uit twee afzonderlijke delen.

**Deel 1** (hoofdstukken 2,3,4) bespreekt ergonomie en efficiëntie-gerelateerde aspecten van de minimaal invasieve chirurgie.

**Hoofdstuk 2** geeft een gestructureerd overzicht van de bestaande literatuur op het gebied van toegepaste ergonomie en laparoscopische chirurgie waarbij gekeken wordt naar de invloed van de positie van het beeldscherm op het werkproces. Zowel aspecten van de productiviteit zoals effectiviteit (optimaal resultaat) en efficiëntie (minimale tijdinvestering) als de aspecten comfort en veiligheid van het arbeidsproces werden geëvalueerd om tot een advies te komen ten aanzien van de ideale monitorpositie gedurende laparoscopische chirurgie.

Verstoring van de kijk-werk as treedt op als gevolg van de beperkte vrijheid in monitorpositionering rond het operatiegebied en wordt gezien als een belangrijke ergonomische beperking gedurende laparoscopische chirurgie. Het opnieuw op één lijn brengen van de kijk-werk as verbetert enerzijds de effectiviteit en efficiëntie van de handelingen van de chirurg en anderzijds het ergonomisch comfort en de veiligheid van de houding van de chirurg gedurende de ingreep. Voor de operateur zullen de factoren effectiviteit en efficiëntie vaak zwaarder meewegen dan voor de assisterende- en instrumenterende leden van het OK team, die, aangezien zij minder laparoscopische handelingen verrichten, voornamelijk belang hebben bij de factoren comfort en veiligheid. In het horizontale vlak wordt axiale rotatie van de wervelkolom voorkomen door de monitor recht voor de leden van het OK team te plaatsen in lijn met de richting waarin ze werken. In het sagittale vlak werkt de operateur het meest effectief met de monitor ver onder ooghoogte dicht in de buurt van zijn werkgebied. De assisterende- en instrumenterende leden van het OK team staan comfortabel indien de monitor net onder ooghoogte wordt geplaatst waarmee extensie van de nek wordt voorkomen.

**Hoofdstuk 3.** In dit hoofdstuk worden de inzichten en richtlijnen die zijn beschreven in hoofdstuk 2, toegepast in de praktijk door middel van een houdingsanalyse van hoofd en nek tijdens de laparoscopische cholecystectomie. De ergonomische situatie in een algemene operatiekamer wordt vergeleken met de situatie in een toegewijde laparoscopische operatiekamer. Voor 16 verschillende operatieteams, allen bestaand uit een operateur, een assistent en een instrumenterende OK assistent, worden op beide type operatiekamers metingen verricht naar de flexie en rotatie van de nek. Daarnaast wordt bij iedere deelnemer een enquête afgenomen naar het oordeel over de ergonomische situatie gedurende de operatie op de betreffende OK. Op de laparoscopische OK is de ergonomische werksituatie voor het hele operatieteam geoptimaliseerd. De houding van de operateur is significant beter in het sagittale vlak (flexie van de nek) en in het horizontale vlak (rotatie van de nek). Voor de assistent wordt een reductie van rotatie van de nek bereikt van meer dan 29° naar ergonomisch aanvaardbare waarden. De flexie is op beide operatiekamers vergelijkbaar. Voor de instrumenterende OK assistent wordt in de laparoscopische OK extensie van de nek significant verminderd naar een ergonomisch neutrale houding. In de enquête waren de scores voor de ergonomische kwaliteit van de werkhouding significant hoger voor de laparoscopische OK en daarnaast gaf het hele OK team aan minder houdinggerelateerde lichamelijke ongemakken te ervaren wanneer zij werken in de laparoscopische OK, waar alle houdingsanalyses binnen ergonomisch veilige marges vallen zoals beschreven in hoofdstuk 2.

In **hoofdstuk 4** wordt de aandacht gericht op de efficiëntie van het operatieproces. Laparoscopische chirurgie vereist veel apparatuur die bij conventionele (open) chirurgie niet nodig is en vaak niet permanent op de OK aanwezig en geïnstalleerd is. Indien laparoscopische ingrepen worden uitgevoerd op een algemene OK moet deze apparatuur voor de ingreep uit de opslagruimte gehaald en geïnstalleerd worden. Na de ingreep wordt de apparatuur weer ontkoppeld en opgeruimd. Dit kost veel tijd en verhoogt de kans op beschadiging van de apparatuur, aansluitproblemen en storingen. Op een laparoscopische operatiekamer is alle benodigde apparatuur permanent aanwezig, geïnstalleerd en klaar voor gebruik. Het doel van het onderzoek uit hoofdstuk 4 is het objectiveren van de efficiëntie van het perioperatieve proces voor laparoscopische ingrepen die worden uitgevoerd op de algemene- en de laparoscopische operatiekamer. In een experimentele setting werden op beide type operatiekamers de opbouw- en opruimtijden gemeten van 3 ervaren operatieteams voor een laparoscopische cholecystectomie (LC) en een laparoscopische sigmoidresectie (LS). Daarnaast werd in de praktijk gemeten of de experimentele data ook in het dagelijkse werkproces tot uiting kwamen. De experimenteel gemeten opbouw- en opruimtijden voor een LC en LS waren op een laparoscopische operatiekamer respectievelijk 2:41 min (39%, $p<0.001$) en 10:47 min (68%, $p<0.001$) korter dan op de algemene operatiekamer. In de praktijk werden deze verschillen ook gemeten voor de werkzaamheden van het chirurgische OK team, echter resulteerde dit niet in een significant kortere wisseltijd als gevolg van de werkzaamheden van de andere disciplines die aanwezig zijn op de OK.

**Deel 2** van dit proefschrift richt zich op methoden en effecten van laparoscopische proceduretraining voor chirurgen in opleiding. Van oudsher worden snijdend medisch specialisten opgeleid volgens het meester-gezel-principe. Hierin toont de meester de verschillende stappen van een operatie en laat dan de gezel geleidelijk delen van de operatie onder zijn supervisie verrichten. Deze methode is weinig uniform en efficiënt. Zodra de meester een stuk van de operatie voordoet, gaat de trainingsmogelijkheid voor de gezel verloren. Om procedure training op de operatiekamer uniformer en efficiënter te laten verlopen hebben wij een nieuwe trainingsmethode ontwikkeld, genaamd INtraoperative Video-Enhanced Surgical procedure Training (INVEST).

**Hoofdstuk 5.** In dit hoofdstuk onderzoeken we het effect van het INVEST-curriculum op de leercurve van een cohort chirurgen in opleiding. Voor een laparoscopische cholecystectomie is een INVEST instructiefilm ontwikkeld conform de bestaande richtlijnen voor deze ingreep. In 7 videofragmenten, die elk een duidelijk te identificeren onderdeel van de laparoscopische cholecystectomie omvat, wordt de betreffende stap

gedemonstreerd en worden anatomische herkenningspunten, technische vaardigheden en potentiële gevaren uitgelegd.
Voorafgaand aan de randomisatie tussen proceduretraining in de OK door middel van INVEST of proceduretraining volgens de meester-gezel methode, werden laparoscopische basisvaardigheden aangeleerd in het skillslab. Op de SIMENDO laparoscopietrainer (SIMENDO, Rotterdam, Nederland) trainden alle deelnemers totdat ze een vastgesteld vaardigheidsniveau hadden bereikt. Na randomisatie voerden de deelnemers in beide groepen 6 keer een laparoscopische cholecystectomie uit waarbij door de supervisor steeds een beoordeling van de vaardigheden gaf door middel van een OSATS (Objective Structured Assessment of Technical Skills). Het leereffect van het curriculum werd gemeten aan de hand van de verbetering in de OSATS-score gemeten vanaf de eerst behaalde score. Daarnaast werd door middel van een vragenlijst de mening van de deelnemers gepeild over het INVEST-curriculum.
In de INVEST groep behaalden de deelnemers een significant grotere toename in OSATS score dan in de meester-gezel groep (32.6 vs. 16,4 punten, p=0.02) en de relatieve groei vanaf de eerste ingreep naar de maximaal haalbare score bedroeg respectievelijk 59% en 35%. In de vragenlijst gaven de deelnemers aan dat zij INVEST een attractieve leermethode vonden, dat het een positief effect heeft op hun leercurve en dat het een uniforme leermethode is. Ze zouden INVEST ook graag gebruiken voor andere operaties. Daarnaast meenden zij met INVEST meer stappen van de operatie te kunnen uitvoeren en dat de supervisor minder hoefde in te grijpen. Dit onderzoek toont aan dat INVEST positief bijdraagt aan het doorlopen van de vroege leercurve van proceduretraining op de operatiekamer. Het leereffect per operatie is significant hoger dan bij de meester-gezel methode. Wat dit onderzoek niet kan aantonen is op welke manier INVEST deze positieve bijdrage levert.

In **Hoofdstuk 6** wordt hier verder op ingegaan. Met behulp van audiovisuele opnames van elke procedure die het cohort deelnemers van hoofdstuk 5 heeft uitgevoerd, wordt een tijd- en taakanalyse verricht. Met deze analyse werd gekeken wat het effect van INVEST is op de beschikbare operatietijd voor de deelnemers en wat het effect is op het aantal stappen die de deelnemer kan uitvoeren. Aan de hand van deze gegevens kon worden bepaald of de positieve bijdrage van INVEST op de leercurve wordt behaald door een verbeterde efficiëntie (de leerling kan langer opereren per ingreep), door een verbeterde effectiviteit (de leerling kan meer stappen opereren per ingreep), of door een combinatie van beide.
In een standaard laparoscopische cholecystectomie werden 14 stappen geïdentificeerd. Een beoordelaar bepaalde aan de hand van geblindeerde videobeelden voor elke stap of deze volledig (2 punten), gedeeltelijk (1 punt), of niet (0 punten) werd verricht door de deelnemer. Daarnaast werden aan hand van de video opnames tijdmetingen gedaan om

te bepalen hoe lang de procedure duurde en welk gedeelte van de procedure de deelnemer respectievelijk de supervisor als opererend chirurg heeft uitgevoerd. Resultaten werden vergeleken tussen de deelnemers in de INVEST groep en de meester-gezel groep voor 6 achtereenvolgende laparoscopische cholecystectomieën.
In de INVEST groep scoorden de deelnemers gemiddeld 116 punten gedurende 6 laparoscopische cholecystectomieën (max 168 punten) in vergelijking met 70 punten in de meester-gezel groep (p=0.009). Hierdoor verrichtten ze van de 6x14=84 stappen er significant meer volledig zelf: 46.6 vs. 18.8, p=0.009. De totale operatietijd verschilt niet tussen beide groepen. Het percentage operatietijd voor de leerlingen in de INVEST groep was significant hoger (69.6% vs. 54.1%, p=0.009). In de operatietijd die beschikbaar was voor de leerlingen, opereerden de proefpersonen in de INVEST groep significant sneller (2.42min/punt vs. 3.32min/punt, p=0.016). Hierdoor is de investering van kostbare totale operatietijd voor de opleiding van deelnemers om een stap van een procedure te verrichten of en punt te scoren significant minder voor proceduretraining volgens de INVEST methode: 5.84min/stap vs. 8.04 min/stap, respectievelijk 3.51min/punt vs. 6.14 min/punt. Deze data onderbouwd de resultaten behaald in hoofdstuk 5 en suggereert dat INVEST zowel door een toegenomen efficiëntie als door een toegenomen effectiviteit een positieve bijdrage levert aan de vroege leercurve voor proceduretraining.

# Dankwoord

# Dankwoord

Na jarenlang ‘bijna klaar’ is het dan nu toch eindelijk helemaal af! De totstandkoming van dit proefschrift is mede aan de volgende mensen te danken:

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# Curriculum Vitae

De auteur van dit proefschrift werd geboren op 5 augustus 1978 te ‘s-Gravenhage. Hij groeide op als oudste zoon in het gezin van Rob, Hilda, Bart en Eric van Det. De middelbare school werd doorlopen aan het Jacobus College te Enschede en in 1996 afgesloten met het eindexamen Gymnasium. Wegens uitloting voor de studie geneeskunde heeft hij een jaar als exchange student doorgebracht in de Verenigde Staten. Van 1997 tot 2004 studeerde hij geneeskunde aan de Rijksuniversiteit Groningen.
Tijdens de studie werd een wetenschappelijke stage gedaan via prof. dr. E.L.G. Verhoeven in het Ashford Specialist Centre te Adelaide, Australië (begeleider dr. J.L. Anderson). De doctoraalfase van de studie werd doorlopen in het Universitair Medisch Centrum Groningen (UMCG) gevolgd door een keuze co-schap Chirurgie in het Medisch Centrum Leeuwarden (MCL), waarna het artsexamen in januari 2004 cum laude werd afgelegd.
Gesteund en gemotiveerd door dr. W.J.H.J. Meijerink solliciteerde hij na het artsexamen met succes voor een gecombineerde onderzoek- en opleidingsplaats binnen de heelkunde. Gedurende de eerste 4 jaar wisselden onderzoek en klinische werkzaamheden elkaar jaarlijks af in het MCL (opleiders dr. W.J.H.J. Meijerink en prof. dr. J.P.E.N. Pierie). In 2009 en 2010 werd het derde en vierde jaar van de opleiding gevolgd in het UMCG (opleider prof. dr. H.J. ten Duis), waarna de auteur voor zijn differentiatie in de gastro-intestinale chirurgie terugging naar het MCL. In het MCL heeft hij de opleiding tot chirurg op 1 juli van dit jaar voltooid (opleider dr. J.S. de Graaf), en werkt hij momenteel als fellow minimaal invasieve chirurgie. Per 1 januari 2013 zal hij vervolgens beginnen aan het gecombineerde CHIVO-schap gastro-intestinale chirurgie in het MCL en het UMCG met het doel dit vak in de volle omvang te gaan uitoefenen en nauw betrokken te blijven met onderzoek binnen dit vakgebied.

# List of Publications

## This thesis

2012 Van Det MJ, Meijerink WJ, Hoff C, Middel LJ, Koopal SA, Pierie JP.
Effective and efficient learning in the operating theater with intra-operative video-enhanced surgical procedure training.
*Submitted*

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