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Video-assisted surgery: suggestions for failure prevention in laparoscopic cholecystectomy

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Abstract

Background: Surgery differs from other medical specialties in its execution. It is often complex and includes considerable individual variations. Observing problems in operating theatres (OT) allows for the identification of system failures which should be defined for learning purposes to increase patient safety and enhance general safety culture within hospital organizations. This study evaluates a common video-assisted surgical procedure, laparoscopic cholecystectomy (LC) through failure analysis. The profile of the LC procedure and failure sources is presented.
Methods: Data consisted video-observations and interviews concerning twelve LC operations performed at a day surgery unit. All operations were teaching sessions. Qualitative analysis was undertaken. Through task analysis, specialist interviews and failure identification a failure profile of LC was produced.
Results*:* Twenty failure types were identified, failures were for example: remote attention towards ergonomics; novice's skill failures; inadequate supervision and unnecessary risk taking caused by tight operating schedules. The results showed that the importance of working principles should be emphasized. The failure profile of LC revealed three phases featuring multiple failures: dissecting the peritoneal covering; identifying, sealing and cutting the cystic duct and cystic artery; detaching the gallbladder from the hepatic bed and inspecting the hepatic bed.
Conclusions: This study offers information for hospital organizations about the current state of surgical work and surgical skills learning. This information could be exploited in the development of system defences: error prevention mechanisms through investing in the redesign of work tasks and working methods; as well as reinforcing education and training for enhancing patient safety in OT.

Key words; *surgical work, laparoscopic cholecystectomy, failure analysis, video-observation, human factors, system failures*

1. Introduction

In modern health care, accidents are caused by both human behaviour and system failures. Constant failure prevention and error management is required for quality and safety improvements. Fortunately, adverse events only rarely result in errors (Barach 2000; Cuschieri 2006). However, error rates are significantly lower in high risk industries such as aviation, nuclear power technology, and military operations compared to medical errors and also the reporting systems on both close calls and errors is considerably more rigorous. Also the benefit of error reporting systems by far outweighs the cost (Barach 2000; Flin et al. 2006; Leape 1994).

It has been estimated that 40-45% of medical errors occur in the OT (Flin et al. 2006; Flin and Mitchell 2009; Tang et al. 2004). Surgery differs from other medical specialties in its execution. It is very complex and includes considerable individual variations. Therefore, errors occurring during surgical procedures are of a unique nature. Surgical performance is a difficult task to systematically measure due to the numerous factors influencing treatment outcomes which are partially independent of the surgeon's experience or skills (Ericsson 2004). Safe surgical practice requires, for example, functional organizational structure and strategic control systems, skilled team work, evidence-based practice, proficiency, continued professional development, advanced information technology, in addition to an active incident and adverse events reporting and disclosure system (Cuschieri 2006).

The problem of human error can be viewed from either a human approach or system approach. The human approach focuses on individual aspects and handles errors as individual causes. In contrast, the system approach sees errors as consequences and concentrates on conditions under which individuals are working (Reason 2000). In human error management the goal is to develop error tolerable systems by targeting the whole system; the person, the team, the task, the workplace and the entire institution (Reason 2000). During recent years attitudes towards surgical errors has changed from a blaming culture and person approach towards a more open learning culture in the direction of a system approach (Cuschieri 2006; O'Connor et al. 2010). Retrospectively observing the problems in OT allows for the identification of failures within the system. Occasionally even small problems during surgery can cause harm or escalate to errors. The detected and perceived weaknesses of a surgical process can be utilized in both error prevention and efficacy promotion of surgical working methods (Catchpole et al. 2008). Therefore, errors and close calls that occur in surgery can and most definitely should be elaborated and discussed for learning purposes in order to increase patient safety and the general safety culture within a hospital organization.

2. Errors and the study of human factors in LC

Minimally invasive surgery (MIS) comprises various video-assisted operation techniques which aim to minimize tissue trauma as much as possible. One example of this is laparoscopy, which is used in numerous surgical procedures and has the benefit of sparing the patients abdominal wall from large openings, which often are a source of early complications and hernia formation. LC is the first MIS procedure taught to resident surgeons in education programs worldwide and the basic skills of MIS should be acquired by this procedure. It is a tissue sparing technique that is not without its challenges: the main concerns are the paradoxical movements of instruments with minimal tactile feedback which are all controlled by the limited field of a two dimensional video camera picture (Bonrath et al. 2013; Conrad et al. 2006; DeLucia et al. 2006). LC additionally involves risks of complications and has an increased serious bile duct injury rate of 0,25 -0,74 percent compared to that of open cholecystectomy which is 0,1-0,3 percent (Nuzzo et al. 2008). The most critical aspects of LC include: the placement of trocars, creating and protecting a clear field of vision, identification of critical anatomic landmarks as well as the dissecting and securing of the gallbladder neck along with its vasculature (Fried et al. 2005; Tang et al. 2004). Since the introduction of LC almost 20 years ago, the complication rates have remained basically the same and bile duct injury is still a serious risk in this procedure (Nuzzo et al. 2008; Ponsky 1991). This procedure takes a relatively long period to learn, as the surgical trainee proceeds under supervision, gradually with increasing responsibility towards becoming an independently operating specialist expert surgeon (Ericsson 2004; Patel et al. 2001; Silvennoinen et al. 2009). Various methods for LC technical skill training for surgical residents have been implemented to aid this learning process such as box trainers and virtual reality simulators (Aggarwal et al. 2009; Ikonen et al. 2012). It is however noteworthy that half of the bile duct injuries occur during LCs that surgeons evaluate as "technically easy." Furthermore, 80% of patients with these injuries do not have any known risk factors, such as anatomical anomalies or gross obesity (Nuzzo et al. 2008).

Through taking a person approach, the individual origins of errors tend to isolate failures within a larger context (Reason 2000). Prior studies on critical aspects of LC have mostly concentrated on technical errors occurring during surgery. For example, Seymour et al. 2004 has defined eight different technical operative errors during gallbladder removal as follows: 1. lack of progress during dissection; 2. gallbladder injury –perforation; 3. liver injury; 4. incorrect plane of dissection – outside the recognized plane; 5. burn to non-target tissue; 6. tearing of tissue – uncontrolled; 7. instrument out of view, tip un-viewable outside the field of view of the telescope; and 8. attending takeover, supervising surgeon takes instruments from the resident and performs a component of the procedure. Seymour's list, in conjunction with other error lists and technical performance evaluations eg. (Bonrath et al. 2013; Tang et al. 2004) presents and describes typical technical errors during LC surgery. Only recent studies on surgical operating errors have realized the importance of human factors awareness (O'Connor et al. 2010). Some studies have concentrated more widely on intra-operative failures as well as small and recurrent system failures relating to surgical procedures (Carthey et al. 2003; Catchpole 2009; Catchpole et al. 2006; de Leval et al. 2000; Spath 2011). In these studies the identification of errors and failures has been made in more detail in order to understand both human error as well as the systemic characteristics that predispose errors, for example in paediatric and orthopaedic surgical procedures.

To design or suggest practices to prevent errors during surgery we should first understand the risks and hazards which may lead to accidents. It seems that for optimal safety in surgical health care, prospective observational multidisciplinary (surgeons and human factors specialists) studies are needed to increase knowledge regarding adverse events during routine surgery. Results obtained from these studies will enable the proposition of suggestions for error prevention (Cuschieri 2006). Compared to other high risk industries, such as aviation and nuclear power, there has been a lack of systematic research on the effects of human factors in surgery (Flin and Mitchell 2009; Weinger et al. 1994; Weinger and Slagle 2002). LC is a well standardized operation, which is complex and prone to errors, and is learned by all surgical residents. This makes failures during LC an interesting subject to investigate. Previously observation has been used as a method for measuring intra-operative interference, such as distractions during LC operations (Healey et al. 2008). The purposes of this study are to investigate LC and create a failure profile of this common procedure while further proposing solutions to manage failures and enhance patient safety. In this paper the profile of the LC procedure and its failures are presented, and introduced further by a discussion on surgical work and training.

3. Study design, data collection and analysis

This study focuses on the sources of threats and errors emerging in day surgical (typical, routinely performed, elective) LC procedures. It also aims at providing insight into how safely these LCs are performed. Research questions are as follows:

a. What are the types and sources of threats and errors in LC procedures?
b. What is the nature of the LC procedure?
c. Which phases of LC are associated with multiple failures?

Video-observations and interviews were the main data collection methods. Video data from 12 elective, day surgery LC operations were captured by the first author simultaneously with four separate cameras. All the video recorded operations were successful and the patients recovered normally. The operations were performed by a total of six surgeons; two expert gastroenterology surgeons, one intermediate level resident and three novice level residents. In each operation the surgeons were working in pairs, one novice and one expert / intermediate level resident was assigned to each surgery. All of the operations were teaching sessions. The combination of surgical team (surgeons and nurses) varied between the operations. The main operator could also be displaced during an operation (attending takeover). Especially if an operation was started by a novice resident whose skills were not sufficient for performing the whole procedure, the senior specialist would conduct the most difficult parts of the operation.

The 12 operations lasted approximately 14 hours altogether, at an average of one hour and ten minutes each. During all operations, the four video cameras were separately capturing the actions of the operator and assistant from the front, hand motions from above the operating table, panoramic view of the whole surgical team (4-6 persons) in the OT, and the laparoscopic camera view inside the patient. The total amount of analyzed video material was 56 hours. For the analysis, all four views were synchronized as simultaneous actions and edited as one display with four video windows.

The qualitative analysis of the video data was conducted. First the general task and behavior analysis, as well as descriptions on each procedure with transcriptions were conducted by the first author. Task analysis (Hollnagel 2012) was used to create a logically advancing description of surgical actions from each 12 operations. This was entered onto separate Excel sheets together with the timeline. Detailed notes of events, activities and communications of the operating surgeons were also written in the sheets.

Secondly, the four expert gastroenterology surgeons were individually invited to watch the videos and were then interviewed by the first author. Each of the 12 operations was watched twice during these interview sessions and they were watched by the two separate expert surgeons. During the video session the expert surgeons were instructed to generally observe and evaluate operations aloud, and to concentrate on highlighting the risks and errors occurring in the procedures. These interview sessions were then recorded and transcribed by the first author. The task and behavior analysis made earlier were then completed with the information gained from the interviews. Subsequently, the expert's comments were added to the 12 separate Excel sheets by the first author.

Thirdly, the failure identification was made from this completed data by selecting and color coding the revealed failure events from the Excel cells. Fourthly, the data from all 12 operations were merged as one single Excel data sheet. This merged data sheet included the procedural list of LC in the first column which was formed by comparing the operation task data. The phases and steps appeared in the analyzed 12 operations, with textbook instructions on how to perform these procedures in the sequenced phases and in the right manner. The identified failures and expert comments were then added to the adjacent column according to steps and phases. Thereafter, the identification of failure types was conducted by applying the failure source models presented by Catchpole et al. (2006) and Catchpole (2009). The failure source components and failure types were added to the next columns. Additionally, the subject involved in conducting the failure was identified either as expert, intermediate, or novice. This process of creating the failure profile of LC is presented in Table 1.

	Procedure description of the phases and steps	**Description of the failure incident (identified failures and expert comments)**	**Failure source component**	**Failure type**	**Subject ; expert /intermediate /novice**
	…				
2.	Creating the pneumoperitoneum and placing the trocars				
2.1.	Creating the pneumoperitoneum	The novice resident begins preparative actions without the supervisor	Cultural / organizational threat	Absence	novice
	…				
2.1.6.	Inserting the first 10mm trocar through the abdomen and removing the trocar blade	The wrong manner to grasp and use the trocar	Technical error	Expertise / skill failure	novice
		…			

Table 1 An example of the data sheet merging the results from the video and interview analyses and failure identification.

In other words, this table was generated by combining the procedural list of LC phases with the identified failures in order to see the whole profile of LC and to see for example which phases in the procedures are associated with multiple failures.

4. Results

The results presented in the next chapters are organized according to the research questions presented previously.

4.1. Identified failure types

The failure identification models presented by Catchpole et al. (2006) and Catchpole (2009) were applied to identify failures from the 12 LCs. Our failure source table formed from the LCs proves fairly similar to the previous results of Catchpole et al. (2006) and Catchpole (2009) concerning orthopaedic and paediatric cardiac surgeries. We slightly modified the original classification based on our results. The differences are elaborated in the following paragraphs. From the LCs we found 20 various failures which are listed in the last column as associated failure types (see Table 2).

Failure source	**Source components**	**Definition**	**Associated failure types found from laparoscopic cholecystectomies**
Threats	Cultural and organizational threats	Threats caused by organization or culture	Absence, distraction, external resource failure, safety consciousness, external pressure (e.g. haste
	Patient threats	Threats relating to patient anatomy and physiology	Patient sourced procedural difficulties
	Task threats	Threats arising from the processes, protocols and techniques employed to complete the operation.	Procedure-related error, equipment / workspace management failure, unintended effect on patient
	Environmental threats	Threats that arise from deficiencies and *"insufficient management"** in	Equipment/workspace management failure, equipment configuration failure, *ergonomic*

		equipment, workspace and resources (human and material).	*failure**, equipment failure, external resource failure
Human errors	Technical errors	Errors associated with knowledge, technical skill or expertise	Expertise / skill failure, psychomotor related surgical error, *ergonomic failure**, equipment configuration failure, psychomotor error (e.g. handling), decision related surgical error
	*Non-technical task related errors **	Errors associated with team working and general cognitive skills	*Ergonomic failure**, procedure related error, coordination / communication failure, decision related surgical error, expertise / skill failure, resource management failure, awareness failure
	*Non-technical judgment errors**	*Errors associated with personal risk taking, judgement and intentional choice**	*Overconfidence, proceeding with known risk**

Table 2 Failure types identified from the 12 laparoscopic cholecystectomy operations were classified by applying and slightly modifying the failure source model of Catchpole et al. 2006 and Catchpole 2009. Our modifications are presented in the table in Italic text.*

The threats presented in Table 2 can be defined as potentially harmful events which may have negative effects on surgical work and materialize, for example as delays, extra work or complications. Cultural and organizational threats emerged in the data for instance as lack of external resources or absence of the supervisor in the beginning of the procedure when the surgical resident was conducting the preparative actions alone. Further, time limitation pressures emerged during most of the procedures. Patient threats were solely procedural difficulties such as anatomical anomalies or extra challenges caused by the level or progression of the disease, cholecystitis. Task threats emerged here mainly as procedural errors made by the surgeons, such as insecure actions when handling surgical equipment. Task threats were also caused by other problems, such as small bleedings or bile leakage. Environmental threats, such as equipment management problems were caused by the lack of the resident's experience to use surgical tools. Yet, in some cases there was also a disorganized stack of pipes and tubes on top of the patient.

Human errors in the Table 2 were divided into three source components. Technical errors emerged mainly in the operations performed by the resident surgeons. These errors often seemed to be caused by lack of skills, such as psychomotor performance difficulties, which result from deficient working methods. In contrast, decision related surgical errors and psychomotor handling errors mainly occurred in operations performed by the specialists and the intermediate level resident.

Compared to the previous failure identifications by Catchpole et al. (2006) and Catchpole (2009) we divided the non-technical errors into two separate categories: task related errors and judgment errors. Non-technical task related errors mainly pertained to team work and general cognitive skill errors. These appeared for example as communication failures between the surgeons or between the surgeons and the other team members. There was also an evident need to more closely examine the judgment failures when perceiving issues such as working against guidelines or generally accepted good practice and ethics. Some incorrect actions emerged as the result of surgeons' evident risky choices, such as prioritizing speed over carefulness which we explicated as overconfidence e.g. (Berner and Graber 2008). These could be seen even as violations when surgeons used a rougher touch to keep up with the tight operating schedule. Another modification we made to the failure identification model was the elaboration of ergonomic aspects in three source components: environmental threats, technical errors and non-technical task related errors. Regarding environmental threats, ergonomic problems were caused by lack of focus towards working conditions such as unergonomic positioning of equipment such as monitors and the patient table. Technical errors sometimes emerged as wrong, risky and also ergonomically challenging work methods. In non-technical task related errors the ergonomic issues emerged as difficult working positions caused by disadvantageously placed tools.

4.2. Procedural list of LC

The procedural list of LC represents the operation phases and steps which should be performed in a typical LC procedure. The list was combined based on both the video analysis results and general literature instructions (Fried et al. 2005; Jänes 2006; Lomanto and Cheah 2004) on how to perform LC. The integration showed how the conduction of the analyzed operations resembles the way that these procedures are presented and instructed in surgical literature. In Table 3 the procedural list is presented on a very general level. In the literature, phases 2-4 were presented in a relatively similar way to our list. However, there were dissimilarities concerning the detailed steps. In our findings the meaning of working principles was more pronounced compared to the literature instructions. Therefore, in our list we added the working principles as separate sub –phases.

Main phases	Sub-phases	Steps included
1. Preparing to operate		
	1.1. Setting up the equipment and focusing on working principles / environment	3
2. Creating the pneumoperitoneum and placing the trocars		
	2.1. Creating the pneumoperitoneum	5
	2.2. Placing the optical trocar and making the first diagnosis	5
	2.3. Placing other trocars	6
3. Operating		
	3.1. Setting up the equipment and focusing on working principles / environment	1
	3.2. Exploring the operative area	4
	3.3. Dissecting the peritoneal covering	2-3
	3.4. Identifying, sealing and cutting the cystic duct and the cystic artery	5
	3.5. Detaching the gallbladder from the hepatic bed, inspecting the hepatic bed	3
	3.6. Removing the gallbladder	6
4. Final check and closing the incisions		
	4.1. Inspecting the operating field and removing the trocars	2
	4.2. Restoring the patient position and closing the incisions	4

Table 3 Procedural list of the phases and sub-phases which should be included in a laparoscopic cholecystectomy operation.

4.3. The failure profile of LC

The failure profile was created by combining failure identification to the procedural list of typical LC. This merging produced detailed descriptions of detected failures within each operating phase. The failure profile of LC enables for the evaluation of differences between the amount and extremity of failures within and between the operating phases. It also reveals whether some phases or steps would appear specifically challenging or more risky than others concerning the manifested failures. Identified diverse failures found from the 12 LC procedures are presented with the amount of different errors and threats in each phase. This means that if in separate operations there were identical failures during the same operating phase, the errors are only registered once in this profile (see Table 4).

The failure profile of LC operation

Main phases	Sub-phases	Failure types	Failures / Sub-phase	Total various failures N

1) 1. Preparing to operate	Setting up the equipment and focusing on working principles / environment	Non-technical errors, environmental & cultural / organizational threats	7	7
2) Creating the pneumoperitoneum and placing the trocars	*Creating the pneumoperitoneum*	Technical & non-technical errors, cultural & organizational threats	7	25
	Placing the optical trocar & making the first diagnose	Technical errors, patient & task related threats	9	
	Placing other trocars	Non-technical & technical & judgment errors, environmental threats	9	
3) Operating	Setting up the equipment and focusing on working principles / environment	Environmental threats, non-technical errors	7	164
	Exploring the operative area	Environmental & patient related threats, technical errors	5	
	Dissecting the peritoneal covering	Technical, non-technical & judgment errors, environmental, task, patient & cultural / organizational related threats	63	
	Identifying, sealing and cutting the cystic duct and the cystic artery	Technical, non-technical & judgment errors, environmental, task & patient related threats	39	
	Detaching the gallbladder from the hepatic bed and inspecting the hepatic bed	Technical, non-technical & judgment errors, environmental, task, cultural, & organizational threats	42	
	Removing the gallbladder	Technical errors, task & environmental threats	10	
4) Final check and closing the incisions	*Inspecting the operating field and removing the trocars*	Technical errors, environmental threats	2	9
	Restoring the patient position and closing the incisions	Technical & non-technical errors, task & environmental threats	7	
Total				205

Table 4 The failure profile of laparoscopic cholecystectomy (LC) procedure with the amount of diverse failures included in the 12 operations

This failure profile shows the accumulation of various failures in phases: 3) operation procedure; and 2) creating the pneumoperitoneum and placing the trocars. Multiple failures emerged in the following three sub-phases: dissecting the peritoneal covering; identifying, sealing and cutting the cystic duct and the cystic artery; and detaching the gallbladder from the hepatic bed and inspecting the hepatic bed. The errors in these phases were mostly technical by nature even though these sub-phases contained the most diverse failures. Environmental threats emerged in each of the sub-phases and several included organizational threats.

If we elaborate these results in sequence, we see that in the first phase, setting up the equipment and focusing on working principles / environment, the errors and threats were solely non-technical, such as ignoring the ergonomic aspects of patient and monitor positions. The operations were regularly immediately commenced when the surgeons entered in the OT. Operating surgeons gave preparative instructions to nurses, for example, concerning the patient positioning, while simultaneously creating the pneumoperitoneum and placing the trocars.

In the second phase, creating the pneumoperitoneum and placing the trocars, the amount of perceived errors increased. This is understandable due to the fact that the duration of this phase is longer. The preparative actions were in most cases performed by the novice surgeon independent of supervision. The specialist entered the OT after the trocars were already placed. However the un-optimal placement of trocars seemed to have a major influence on the decreased fluency of the operations. Technical errors in this phase were mainly skill failures of the novice surgeons. Non-technical errors conducted by the both novice and experienced surgeons were e.g. procedure related errors, such as lack of safety checks. Based on the expert interviews, judgment errors emerged here as evident risky choices of actions taken by the operating surgeons, in other words proceeding with known risk.

In the third phase, actual operating, where the gallbladder is detached and removed, the expert observers analyzing the operations focused at first solely on environmental threats. The reasons for this could be seen in the previous preparation phase. Disorganized pipes and tubes, ergonomically incorrectly placed monitors, fuzzy monitor picture, incorrectly inserted trocars and insufficient lighting caused e.g. ergonomic problems to the both operating and assisting surgeons. Technical errors again consisted of novices' skill problems resulting from deficient instrument handling. However, instruments slipping in wrong directions and causing small, yet non-life threatening bleedings occurred sometimes to more experienced operators as well. Several overconfident working methods were perceived, such as using the electro cautery incorrectly, working carelessly too close to vital organs, or grasping tissue in a rough manner. Hurry to proceed was shown both in the actions of surgeons and nurses which reflected on team work. Typical workspace management failures were a blood stained camera picture or too small space to operate while the camera and instruments were crossing impractically inside the abdomen. Some operators did not precisely follow the protocol presented in the literature instructions. Furthermore, some safety checks were missed and plenty of technical equipment malfunctions occurred during the procedures causing delays and instigating further time pressures for the whole surgical team. Some operating instruments in this particular OT differed from the equipment in other OTs causing extra challenges to the surgeons who mostly operated in another OT.

In the final phase it was normal that the specialist surgeon left the novice to close the incisions on their own. Several ergonomic problems emerged in this phase, though the resident surgeons seemed to settle for a casually adjusted table and inadequate lighting. In seven operations out of 12, the expert observers noted an inadequate examination of the operative area prior to closing in order to detect any bleeding or bile leakage.

5. Discussion and suggestions for failure prevention in OT

After surgical operations the great majority of patients recover normally without any complications. However, in surgical tasks harmful incidents are invariably preceded by undetected close calls and unnoticed small errors which involve the risks of harming the patient. (Catchpole 2009; Catchpole et al. 2006). Also the results of this study indicate that several failures which occur during surgical operations remain unnoticed by the surgical teams. The wide diversity of safety aspects in the 12 operations, at a total of 205, was noticed indicating at least some risk of errors and complications. Our results are not divergent compared to the findings of other similar studies. Catchpole (2009) for example found 327 failures from 14 knee replacement operations, even though the results are not comparable quantitatively due to multiple uncontrolled variables.

20 various failure types, both threats and human errors, were identified in this study. Failures were for example: remote attention towards ergonomics, novice's skill failures, inadequate supervision and unnecessary risk taking caused by the tight operating schedules. The most common failures seem to be related to distractions, equipment and workspace management, in addition to safety consciousness (Catchpole 2009). Safety culture defects in our study were, for example, the disorganized operating table filled with tools, insufficient lightning, or inadequate usage of the available instruments and a blood stained camera picture. Rather similarly in the observation study of Healey et al. (2008) the sources of distractions and interruptions that occurred during surgical team work derived from

working environment, equipment's and procedure related issues. Threats that were probably caused by the organizational issues and working culture in OT emerged in our study for example as external organizational time pressures. There seem to be a need to proceed or to act with haste, the absence of a supervisor at the beginning and end of the operations emerged, and distractions such as a phone ringing and call being answered during operating. These issues are indirectly affecting to surgical safety and the tight schedule may cause surgeons to prioritize efficiency over carefulness. Closely related to issues of safety culture emerged the non-technical errors associated with personal risk taking, judgment and intentional choice. However, some of the overconfident actions seen in these procedures were likely reactions to uncertainty concerning the anatomy which caused difficulties to proceed safely and systematically according to protocol. Other threats seem to pertain to unfamiliar equipment. Threats arising from the processes, protocols and techniques were also at least partially related to time limitations.

In this study the lack of focus in equipment arrangements, working principles and ergonomics emerged similarly to what is witnessed in the surgical literature instructions designed to teach LC. Procedural list, the phases and steps to perform LC showed that the studied procedures were mainly conducted according to the literature instructions. However, adding a specific preparation phase to the instructions which highlight the meaning of working principles in the beginning of the procedure description before placing trocars, could be beneficial. This is supported by the prior studies arguing that the majority of surgeons and residents are unaware of ergonomic practices and guidelines, even though they realize the importance of ergonomics during video-assisted operations (Gawande 2003; Wauben et al. 2006). Ergonomics and environmental factors have proven critical in avoiding fatigue, concentration problems and human errors in OT and the ergonomics of training setting greatly influence both task performance and skills learning at least in simulated operating settings (Emam et al. 2002; Xiao et al. 2012).

The profile of LC revealed the operation phases involving various risks and challenges. It also enables the evaluation of differences between the amount and extremity of failures within and between the operating phases. The failure profile presented in this study shows the accumulation of failures in two main phases, as well as in three of the sub-phases. The errors in these phases were mostly technical, as were the eight errors presented earlier in Seymour's list (Seymour et al. 2004). What Seymour et al.'s study tried to accomplish was the development of a simple and reliable analysis tool to define behaviors leading to adverse clinical outcomes. They argued that important information can be produced for surgical educators from the effectiveness of training methods and residents' competencies by defining, identifying and measuring errors (Seymour et al. 2004). What Seymour et al. (2004) might have even intentionally ignored was the deeper error mechanisms. In our study, we looked deeper into errors and threats, towards causes, mechanisms and failure sources. Our results showed that most failures accumulated in the phases which were technically challenging. Failure profile also showed in sequence how the occurrences in OT lead to failures, how the unsupervised and incorrect placement of trocars in the beginning influenced on the fluency of procedure and incorrectly inserted trocars in combination with insufficient lightning caused ergonomic problems to surgeons. Errors are products of a chain of causes and a combination of several factors which are always affected by the local circumstances, individuals and environment of action (Reason 1997; Spath 2011). Therefore, it is not straightforward to assess skills or competence by looking at technical errors. There are various background factors and sources influencing threats and human errors in each situation: organization and culture, the patient, the task, the environment around us, in addition to individual technical and non-technical abilities. Errors and their causes and mechanisms are difficult to analyse and evaluate. The incidents and occurrences inside individual OT are connected with the wider context and therefore finding the initial solutions to problems and improving surgical work and safety require understanding also the wider organisation context beyond an individual or team performance for example on how the organisational learning or workplace learning is supported at hospital (Xiao et al. 2008; Tynjälä 2008).

In our study the remote preparative instructions for the team were expressed casually. Also Gawande et al. (2003) found that organizing, planning and interaction among team members prove critical yet underappreciated factors contributing to errors. We argue that greater highlighting the importance of preparative actions, team working and communication, could result in diminished equipment, ergonomic- and task related errors and failures. In addition to the standardization of processes, protocols and techniques, hospitals should invest in equipment to avoid malfunctions. The need for allocating more training time to the whole surgical team on equipment management and handling should be considered. Concentrating on these issues further might also then lead to positive influence on the fluency of operations and timesaving. In high reliability organizations errors are expected and workers are trained to recognize and recover from them (Reason 2000). Instead it now seemed that time was tried to be reduced by deliberately shortcutting protocols and missing checks to proceed faster. It has also been found that the accuracy of reported intraoperative notes on LC contains only one-quarter of the steps actually including in LC, which indicates that aforementioned shortcutting is made also in reporting e.g. (Wauben et al. 2011). These issues could be considered as problems relating to standardization. Again, when the novice surgeon was proceeding without the supervisor we assumed that the checks were missed unintentionally. Our results resonate with the interview study of Gawande et al. (2003) where surgeons self-reported the most common systems factors contributing to surgical errors as being inexperience/lack of competence in a surgical task (53% of incidents). Furthermore, the two most commonly cited cognitive factors influencing error were vigilance failure (62% of incidents) and judgment error (52% of incidents). They also suggest that errors in judgment are strongly associated with reports of inadequate supervision.

Surgery is expensive and today health care is seeking cost-effectiveness. A considerable cost factor in surgical training is operation time (von Strauss und Torney, M et al. 2012). Therefore, OT is not an optimal place to teach the basics of complex procedures such as laparoscopy. It requires time, repetition and deliberate practice to learn to accomplish these procedures independently (Brunner et al. 2004; Ericsson 2004). Further, training with patients has also become more or less unethical since the introduction of simulator training possibilities (Ziv et al. 2003). Instead, the basic surgical skills should be acquired and mastered by residents before entering the OT e.g.(von Strauss und Torney, M et al. 2012). Resident education should involve curricula with simulation training and check points, or exams and feedback. The procedural list, for example, could serve as a learning tool for residents to acquire knowledge of LC procedure protocol. The list may also be applied as the framework of a checklist or assessment tool when teaching or evaluating performance. Residents entering OT should have adequate knowledge and skills at least in the following areas:
- patient anatomy and physiology
- technical skills such as fluent equipment handling and usage
- working environment issues and ergonomics
- non-technical skills such as decision making, team working and communication

Finding the best practices requires careful consideration of methods and places for training surgical competencies. For example, consideration should be made in terms of the parts of training that should be realized outside operating theatres and which parts are essential to conduct in authentic situations (Silvennoinen et al. 2009). In fact, learning professionalism (tacit knowledge) in surgery, such as attitudes, values, and behaviors, good role models in the form of specialist instructors are an important force influencing residents' professional development (Park et al. 2010). Role modeling should also be offered structurally within training programs through demonstration, as well as in everyday work enabling learning through observation, reflection, and reinforcement (Park et al. 2010).

Video-based research has been generally used in human factor research; even though the methodological challenges are commonly encountered when observing human performances in an uncontrolled environment. High-risk domains such as surgery could clearly benefit from this kind of rigorous investigation (Guerlain et al. 2004). Although assessment of surgical competence through observing errors is not straightforward, performance evaluation has been proven to be beneficial for discovering aspects that need training and improvement e.g.(Ericsson 2004). Guerlain (2004) also reminds that there are technical, social and financial challenges to overcome when using this type of investigation. In this study these issues were focused through careful planning, using high quality technology, informing the participants properly and using confidentiality agreements. In the analysis process the false names and numerical codes were used in the Excel material, to hide the operating surgeon's identities. Our analysis tool, the failure identification model was practical to apply, even though the classification of failures sometimes felt artificial and some failures could have been classified into several diverging categories. The decision to conduct qualitative analysis on a data driven bases was made here consciously since there were too many depending variables that these operations would be comparable statistically. The strength of this qualitative analysis is that it offers detailed and rich description of the cases and complex phenomena of surgical performance as it occurs in natural contexts enabling also analysis of causes and effects of occurrences (Patton 2002). However as a limitation or this study it is also possible that there were failures occurring in these cases that neither authors nor expert observers noticed. Concerning the trustworthiness and credibility of data and this qualitative analysis, in this study a relatively large amount of data was gathered. However, by applying the failure identification model to our elaborated data a holistic illustration of different failures and their main leading causes in LC surgery was accomplished.

6. Conclusion

This study describes day surgical LC in fine detail and reveals the nature of the procedure as multidimensional and challenging for the surgical residents to perform. This study aims at informing surgical teams and hospitals on failures occurring during common surgical procedures which might remain unnoticed during surgical work in OT. Both surgical teams and hospital organizations should even more consider the issues effecting the working and teaching culture as well as team behavior in OT. Considering and studying the task patterns and factors that affect performance during patient care may lead to improved outcomes and diminish harmful events as a result of rethinking and redesigning work tasks and systems (Flin and Mitchell 2009; Hollnagel 2012). Based on these study results, in order to develop systems, focus should be on two overlapping issues: *organizational and cultural aspects* as well as *educational aspects*. It is relevant to ask whether the amount of failures occurring in OT could be efficiently diminished by systems redesign or education. We suggest that these results should be exploited while further developing error prevention mechanisms such as surgical education and training curricula for learning and reinforcing skills and knowledge. Additionally, organizational arrangements for enhancing the safety culture in OTs should be standardized.

In systems development and redesign, discussion on system level failure sources is much more beneficial than discussion on individual details and quantities. We hope that this paper brings new ideas to hospital administrations concerning the development of surgical work environments, as well as surgical skills and teams' education. Learning not only from mistakes, but also from close calls and potential risks is an important resource for the future of surgical safety culture development. Threats are as important as errors while discussing the sources of failures. According to the system approach "if we cannot change the human condition, we can change the conditions under which humans work" (Reason 2000). We argue that by looking at these contextual issues, we can find the key elements for systems development and through changing the course of actions it might be possible to diminish the probability of failure occurrence. Educational considerations regarding the amount and quality of training are required. Additionally, they call for the maintenance and further development of skills while working as a specialist. Various means, such as simulator training should be used to guarantee adequate practice opportunities outside OT. Even though this might prove more difficult for influencing cultural and organizational aspects in comparison to individual training possibilities, these factors are equally important and intertwined. Failures are of different types and have different kinds of psychological background mechanisms, which result also in different requirements for prevention management. When investigating failures and errors in healthcare, we most of all need an understanding of why errors occur and how they can be prevented. Therefore, besides understanding the systems, also understanding of human factors and performance is valuable as well. Future studies should concentrate more on elaborating human error mechanisms, even though we should additionally acknowledge the psychological theories regarding why and when people make mistakes, unintended human acts and how these mistakes can be prevented.

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Comments reviewers	Authors response
Reviewer #1The sample is very modest, and the authors should be more cautious in their claims about the value of their findings and their generalisability.	The strength of this study is qualitative approach which offers detailed and rich description of the cases and complex phenomena of surgical performance as it occurs in natural contexts. Analysis of causes and effects of occurrences was possible this way. However the limitation of this kind of analysis is that it might be influenced by the researcher's personal biases and attributes. There is also difficulty of doing any quantitative readings. The interviews of surgical experts who were very familiar with performing these kind of procedures provided additional viewpoints (two different experts watched each operation). These completed the author's analysis and diminished the bias of researcher's interpretation of events. To assess the generalizability of this study we argue that the intention was to elaborate the phenomenon through case analysis. The results we found were parallel with what other studies have found (similar kind of failures during surgical operation), however we have here also highlighted that there are always local circumstances and individual factors involved when investigating errors and wider context to consider. (end of page 10) Having two experienced surgeons here as co-authors who were very familiar with this explored procedure and teaching laparoscopic skills in OT compensated the first author's lack of surgical knowledge.
Reviewer #1The value of this paper is in providing some results which converge with other similar studies (notably Guerlain's work and Catchpole's), but more so on testing further the feasibility and validity of the methods used. The authors might consider placing greater emphasis on the latter in their discussion.	The authors have familiarized themselves with the work of both Guerlain and Catchpole studies very carefully when conducting this study and writing this paper. The methods evaluation section in the discussion has however been extended and elaborated further which hopefully clarifies more the method and choices that the authors made relating that.
Reviewer #1the authors should also consider other papers that focus on methodology, for the reason stated above. Xiao, who the authors do reference, has concentrated on the video-observation method and has published other papers.	See comments above. We also added methodological considerations in the end of the discussion part (page 12, before Conclusion).
Reviewer #1There is also a wider context to the assessment of the surgical [sociotechnical] system, for which there is a Special Issue in this journal (2009); authors include Xiao, Guerlain and	The wider context is very good point to be highlighted. The authors have explored this Special issue and found it helpful in this matter. The references relating to this issue are cited in following parts: End of Page 9 (Healey 2008), Top of page 11 (Xiao 2008)

Catchpole. The authors of this paper should consider this Special Issue and cite relevant papers within it, where appropriate.	
Reviewer #4: Some typing errors need to be corrected, especially when lists are used (e.g. page 3, line 27 & 28, when symbols square symbols appears).	Typing errors in these text parts has been corrected.
Reviewer #4: From the methodological point of view two fundamental aspects, in my opinion, should be introduced and expanded in order to make it more critically discussed: 1. the analysis of 12 operations can be considered statistically significant? 2. it seems that the task analysis and the identification of errors is based only on the observed "failed actions": are the authors sure that all the possible failures (even those not observed during the 12 operations) have been taken into account? Usually the task analysis is used firstly in a "perspective mode" to identify all the possible expectable failures, to be used as a basis to examine real cases in a "retrospective mode"	Point 1. The analysis performed in this research was not quantitative which was a deliberate methodological choice made by the authors as we conducted the research from data driven basis. There were too many depending variables that these operations would be comparable statistically. (this was earlier mentioned in page 9, line 48 and now further clarified in the end of discussion)Concerning the trustworthiness and credibility of data and this qualitative analysis, in this study a relatively large amount of data was gathered. The transcriptions and video edition was made meticulously. The analysis process was multiphase and data interpretation errors were tried to minimize by using the experts as central informants, a kind of research triangulation. The authors argue that the richness of the data was considerable. Reliability of coding and pattern analysis was reinforced by selecting rigorous methods such as the failure analysis model recommended and used in other surgical behavior studies. Point 2. in this study the authors were not trying to cover all possible failures, instead we tried to describe and understand the nature of typical elective LC performed in day surgery and explore the failures involved in this type of operation. It is possible that also other and different kind of failures might occur if the operation was an emergency case. It is a very good point to consider, relating the study evaluation, that it is also possible that there were failures occurring in these cases that neither authors or expert observers noticed, this argument is added to the text in the end of discussion, in page 12. In further studies it would be interesting to perform also this kind of quantitative retrospective study with larger data to explore the quantity of failures occurring during LC. However here the approach was different from what the Reviewer #4 refers to.
Reviewer #4: The chapter of discussion and suggestions is very interesting but merges different topics: I think that it became more easy to the reader if it would be a little more structured.	This was very valuable comment. The structure of the discussion (and also conclusions) has been edited and is now differently formatted with more structure as the Reviewer #4 suggested.