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**Author:** Spruit, E.N.  
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CHAPTER 02

COGNITIVE TASK ANALYSIS
OF LAPAROSCOPIC SIGMOID
COLON RESECTION:
TOWARDS A STANDARDIZED
CURRICULUM FOR
TRAINING LAPAROSCOPIC
SURGERY

Edward N. Spruit MSc.
Tom Hulscher MSc.
Dr. Guido P.H. Band
Prof. Jaap F. Hamming
Abstract

Background: The complexity of laparoscopy has raised the urgency for standardizing the associated curriculum. We used cognitive task analysis (CTA) on laparoscopic sigmoid colon resection to identify essential action steps, decision points and key skills.

Methods: A cognitive task analysis was performed using literature, interviews, video, and observations in the OR of laparoscopic procedures. Video-recorded semi-structured interviews were held with seven experienced surgeons from various medical centers in the Netherlands.

Results: A procedural checklist was established that contains seven sub-tasks, 41 operative steps and seven decision points. The difficulty of each operative step and decision point was rated (novice, intermediate, advanced) by a panel of experienced surgeons. The CTA was used to create a surgical skill profile that can guide the design of a standardized curriculum for training residents.

Conclusions: The surgical skill profile and procedural checklist can serve as a framework for standardized training and assessment of laparoscopic skills.
Introduction

Laparoscopic surgery (LS) differs substantially from open forms of surgery in its cognitive demands and the complexity of perceptual and motor skills (Gallagher & O’Sullivan, 2011). For example, instruments can only reach the organs through trocars in the abdomen, which limit the freedom to move, while vision is limited by the orientation of a camera and the two-dimensional display. Therefore, preparing surgical residents for their first LS on patients requires efficient and thorough training based on a detailed understanding of the challenges involved. It is in the interest of both patient safety and the expenses of medical training that all residents follow a well-defined, optimized and evidence-based curriculum based on principles derived from cognitive and education science (Friedlander et al., 2011; Hodges & Kuper, 2012; Levinson, 2010).

As an important step towards standardizing the curriculum of residents acquiring LS skills, a cognitive task analysis (CTA) of LS is reported. This method has been used effectively in the past to analyze colonoscopy (Sullivan et al., 2008), laparoscopic appendectomy (Smink et al., 2012) and laparoscopic Nissen fundoplication (Peyre et al., 2009). In this paper we applied CTA to analyze advanced colon surgery. The CTA results consist of a step and decision checklist for laparoscopic sigmoid colon resection and a surgical skill profile that can serve as a guide for designing the associated training curriculum.

Method

Cognitive Task Analysis (CTA)

In order to establish a standardized curriculum for LS, we performed a CTA to chart which specific skills residents need for LS, and what they should be trained in. It included reviewing literature, analyzing recorded videos of laparoscopic procedures, observing operations in the OR and conducting video-recorded semi-structured interviews with seven experienced laparoscopic surgeons from several medical centers in the Netherlands. Automatized performance following years of experience often prevents experts from articulating all the required concepts, cues, action steps and knowledge, because the task has become second-nature to them (Clark, Feldon, van Merriënboer, Yates & Early, 2008). CTA provides research techniques that can be used to elicit this covert knowledge and capture the cognitive decision-making processes that experts utilize while performing a task. This can be done by asking probing questions and process tracing in a semi-structured interview (Clark et al., 2008; Militello & Hutton, 1998). In this way, CTA can help to capture the goals, steps, decision points, skills, knowledge and demands that are essential to the safe and successful completion of a laparoscopic operation.
The CTA was applied to three types of LS: laparoscopic cholecystectomy, laparoscopic fundoplication and laparoscopic sigmoid colon resection. For this paper, we focused on sigmoid colon resection in depth and will use it as the exemplary case of LS. Although most tasks during LS are performed sequentially, as summarized in the procedural checklist in Appendix A, additional tasks continue throughout the operation, such as team communication, monitoring the operating field, and adjusting the pace of the procedure. Based on the CTA, we established a set of key skills for LS, which can be found in Appendix B. The first part of the article covers the analysis of laparoscopic sigmoid colon resection. The second part describes a skills profile of what makes for a proficient laparoscopic surgeon and offers brief suggestions for how these skills may be integrated into a curriculum for surgical residents.

**Laparoscopic Sigmoid Colon Resection**

Laparoscopic colon surgery is an advanced form of surgery, which a surgical resident learns to perform in later stages of training after basic skills and procedures have been mastered. In this analysis, we focused specifically on laparoscopic sigmoid colon resection for the treatment of cancer.

**Operative Steps and Decision Points**

From the Cognitive Task Analysis, we were able to divide the operation into seven sub-tasks with 39 operative steps of which six are optional or dependent on the given conditions. Seven decision points were identified for the procedure. The full list of operative steps and decision points can be found in Appendix A.

The procedure starts with patient positioning and trocar placement, a sub-task that is very similar for most laparoscopic procedures. After this has been established, the surgeon investigates the abdominal cavity for potential abnormality of other organs or the peritoneum and accesses the local tumor status. In the case of advanced local tumor growth, the surgeon may opt to convert to laparotomy. In the majority of cases, a medial to lateral approach is used for the sigmoid dissection.

Blunt dissection in the avascular layers of the sigmoid mesocolon is initiated to create a submesenteric window (tunnel) in order to expose sensitive structures like the left ureter and the hypo gastric nerve. When these have been identified, the artery supply that supplies the sigmoid colon is dissected first. This ‘vessels-first’ approach is a common oncological principle to limit potential tumor cell dissemination. The sigmoid arteries need to be dissected in proximal direction so that at least twelve lymph nodes are attached to the extracted colon specimen.
In the sub-task that follows, the posterior and lateral attachments of the sigmoid are mobilized. If there is a tension-free fit of the proximal and distal end of the remaining colon for anastomosis, no further mobilization is needed. If there is not enough slack however, the descending colon and splenic flexure must be mobilized to create more length on the colon. The need for further mobilization of the colon varies among patients and is also influenced by the location of the tumor. If more length is needed, the descending colon is mobilized laterally at first and medially if necessary. Some surgeons always mobilize the descending colon as a protocol. When a tension-free fit is achieved, the colon can be divided distally at a minimal margin of five centimeters below the tumor. After this, the proximal colon is extracted outside the abdomen, divided proximally five centimeters above the tumor while also taking into account the artery supply.

In the final sub-task, the anastomosis of the proximal and distal colon is created. If desirable, a deviating ilieostoma is created and the anastomosis is tested for leakage. If necessary, the mesocolon is closed to prevent a potential herniation.

**Anatomical landmarks and hazard zones**

The most important structures to preserve in this operation are the left ureter and the hypogastric nerves. In case of upward mobilization, the spleen and pancreas are anatomical landmarks. Also, care must be taken not to damage the colon itself. Furthermore, correct identification of the inferior mesenteric artery and its three most important branches (the arteria colica sinistra, the trunk of the sigmoid arteries and the arteria rectus superior) are very important.

There is the choice between doing a high-tie or low-tie ligation of the blood supply to the colon. A high-tie implies dissecting the inferior mesenteric artery and thereby take out all its branches, whereas a low-tie implies only ligating those arteries that supply the part of the colon that is going to be extracted (Lange, Buunen, van de Velde & Lange, 2008). For optimal vascularization of the remaining colon, the low-tie procedure is preferred.

**Individual case variability**

There are anatomical variations between patients. For example, patients from developed countries who eat a lot of red meat tend to have a lengthier colon, which makes the necessity of upward mobilization less likely. Also, the procedure tends to be facilitated in lean patients who have a low-level of intra-abdominal fat. In these patients the arteries of the sigmoid mesocolon are much easier to identify. For the same reason, the operation tends to be easier to perform on obese women, as female patients usually have more subcutaneous rather than intra-abdominal fat in comparison to obese men. When the medial mobilization and ligation of the arteries becomes too troublesome, a surgeon
may opt to use a lateral-to-medial approach in difficult cases. Awareness of individual differences is important to teach to surgical residents.

**Surgical Skills Profile**

One of the main incentives for the introduction of LS has been to limit damage to bodily tissue (Hamming, 2005), while still achieving all objectives of surgery. The combination of these two goals defines surgical proficiency. A more detailed profile of surgical proficiency was derived from the CTA. An overview of this skill profile is displayed in Appendix B. Each point of this proficiency profile and its place in training will be discussed briefly in the remainder of this article.

**Surgical Knowledge**

Surgical knowledge consists of semantic knowledge regarding anatomy, pathology and procedural steps. Semantic knowledge refers to general knowledge that has validity across different situations. It is typically acquired through books, lectures and educational videos. Knowledge of anatomy and physiology is an obvious prerequisite for LS. Insufficient knowledge could lead to incorrect decisions and errors with dramatic results, as the surgeon needs to know where incisions can and cannot be made safely. Valuable suggestions for the anatomy curriculum have been made in literature (Kooloos, de Waal Malefijt, Ruiter & Vorstenbosch; Sugand, Abrahams & Khurana, 2010).

Regarding knowledge acquisition, it is notable that educational psychology suggests ways to optimize learning, which are not yet commonly implemented in medical curricula. For example, prolonged retention of knowledge is achieved by distributing the same study time over an extended period and by interleaving different types of practice problems (Dunlosky, Rawson, Marsh, Nathan & Willingham, 2013; Rohrer & Pashler, 2010). However, the medical curriculum typically works in dedicated thematic blocks (minimal spacing and interleaving of study material), which is suboptimal for learning efficiency.

Declarative surgical knowledge, that is, explicit knowledge of the steps to go through for each LS type, is relatively easy to acquire, even without practical training. Furthermore, because of the consistency inherent in most LS protocols, retrieving the order of steps from declarative memory can be easily trained to perfection. In contrast, procedural knowledge, that is memory for actions that cannot be articulated (such as LS motor, perceptual and clinical decision making skills), has a shallow learning curve.

Acquiring procedural knowledge is facilitated by using worked examples: initially, the structure of a problem to solve can be simplified by step-by-step demonstrations (van Merriënboer & Sweller, 2010). Because worked examples involve a modest cognitive load during training, residual processing capacity remains available for the actual learning
process, rather than all being used for understanding one’s own actions or instructions. Likewise, for complex tasks, there is a benefit to first learning parts of a task before learning the task as a whole, provided that the elements learned are independent (Teague, Gittelman & Park, 1994; Wightman & Lintern, 1985). This experimental finding argues against immersion of students into the full complexity of LS in the starting phase of their training (Spruit, Band, Hamming & Ridderinkhof, 2014, see chapter 3).

Perceptual skills
During surgery, various types of tissue respond differently to being dissected. Some tissues are avascular and can be dissected easily, while others will bleed more readily. Many of our experts stated that an operation is much easier to perform if one stays in the proper planes and areas during dissection. A clear example of this is when surgeons are creating the submesenteric window during laparoscopic sigmoid colon resection or dissection in the Total Mesorectal Excision (TME) plane during rectal resections. Because of this, being able to identify the different types of tissue is crucial in completing a surgical procedure and minimizing damage. This perceptual skill is the result of many years of experience in the operating room, although it can also be trained in anatomy labs.

Technology is currently in development that can distinguish between different types of tissue (mesenteric fat, blood vessels, colon, ureter, tumor) and can be implemented as an image enhancement aid during colorectal surgery (Schols, Dunias, Wieringa & Stassen, 2013). Similarly, our panel of surgeons stated that color marking techniques are already used in order to spot the tumor more easily during colon resection. There is a realistic expectation that technology will facilitate more accurate identification of tissue in the future.

Additionally, there is potential for e-learning for acquiring the skill of identifying different tissues. For example, recorded footage of laparoscopic procedures may serve as a medium for teaching surgical residents how to identify different kinds of tissue and anatomy, if the footage is edited and highlighted in a way that facilitates the learning of this skill.

The ability to form a clear mental picture of the kind of action to be performed is indispensable to a surgeon. This skill (Jeannerod, 1995) involves creating a mental image of the end state that is to be achieved as well as a mental representation of the motor action required to achieve that end state. A practical example of this skill is knowing exactly what the optimal angle is to grasp a needle so one can set it up perfectly for making throws during laparoscopic suturing. With practice, the surgeon will acquire enough reference experiences to immediately retrieve the most efficient action representation to grasp the needle optimally for a smooth completion of the task (Logan, 1988).

Adapting to reduced tactile feedback and depth cues occurs during basic laparoscopic skill courses using Virtual Reality (VR) - and physical box-trainer simulators or in porcine
models. A common complaint about VR-simulators is that tactile feedback is lacking and even for the ones that do provide it, surgeons often perceive the feedback to be unrealistic (Våpenstad, Hofstad, Langø, Mårvik & Chmarra, 2013). Recently, measures have been taken to improve tactile feedback on instruments in a physical box trainer, which can lead to positive effects on grip force and tissue handling (Horeman, Rodrigues, van den Dobbelsteen, Jansen & Dankelman, 2012; Wottawa et al., 2013).

**Motor skills**

A cornerstone of surgical proficiency in laparoscopy is motor skill, since the used instruments are different from open surgery. Adapting to the fulcrum effect (the fact that instruments move inversely in- and outside the abdominal cavity) and familiarity with the instruments form the basis of motor skill.

The correct application of motor skills is highly intertwined with the surgical knowledge a resident has and the quality of the (processed) perceptual input that is coming in. Hence, proficiency in motor skills, though essential, is no guarantee of adequate application of those skills during surgery. Without sufficient practice, such skills decrease rapidly (Gallagher, Jordan-Black & O’Sullivan, 2012). This has been reason for the Dutch endoscopy society to prohibit infrequent LS performance (Bemelman, 2009).

Because the images coming from the laparoscope are magnified on a screen, the motions a surgeon makes with instruments are also magnified, leading to amplified tremor, another challenge a resident needs to master. Surgical accuracy can be improved with motion scaling by means of robotic surgical systems (Prasad et al., 2004), although its application in most hospitals is limited due to high expenses of surgical robots and also because it is still unclear whether or not the use of robots in the OR will lead to superior outcomes for patients in comparison to conventional techniques (Wiklund, 2004), a common issue with the introduction of new technology in healthcare.

Basic motor actions include mobilizing tissue for exposure and dissection, blunt and sharp dissection, use of devices (cautery, ultrasonic shears, LigaSure, stapler), intra-corporeal suturing and additional techniques (such as the use of umbilical tape, meshes and extraction bags in various procedures). Most of these motor skills can be adequately trained during specific courses on LS and in most teaching hospitals that have a skills lab with laparoscopy training setups like physical box-trainers, virtual reality simulators or porcine models (Aggarwal, Moorthy & Darzi, 2004).

For optimal training design of a laparoscopic motor skills program, factors such as proficiency benchmarks, spacing, adaptive training, task variability, part-task training, mental imagery, dual-task training and goal-directed deliberate practice should be taken into account (see Spruit et al., 2014 (chapter 3) for an in-depth review).
Clinical decision making
In medicine, physicians have to make important decisions about choosing or not choosing different treatments on the basis of a patient’s symptoms, the outcome of diagnostic tests and probabilities (Kassirer, 1976). During surgical procedures, this decision making is expressed in the art of knowing how and when to apply certain skills in order to facilitate a positive outcome for the patient. It is knowing when to switch to another task or when to inhibit an automatic response when an unusual case presents itself. This form of proficiency can be viewed as a combination of faculties that determine what stage the operation is at, monitor the perceptual input that is coming in, and pick a course of action to proceed with accordingly. In this way, the procedure is directed to meet the two primary goals (achieving the objectives of the operation, while minimizing damage) in the most successful manner that is possible given the current level of the surgeon’s proficiency and the current external conditions. According to our panel of experts, proficiency in this skill is the result of years of practical experience. When humans are engaged in a task, they tend to make decisions intuitively in-the-moment and reflect on them after completing the task. Especially in emergency situations, surgeons need to be able make snap judgments on what to do in order to respond fast and accurate. There are exceptions to this, as was reported by surgeons in our interviews. In some circumstances, a surgeon may opt to take a short break in the operation to consciously reflect on the next course of action. For example, when a procedure progresses differently from what was initially expected, it may be a wise decision to stop and pause in order to think thoroughly about how to adjust the plans for the rest of the operation. Nevertheless, the actual decision to know when to stop and take a short break still classifies as a form of intuitive clinical decision making that comes with experience. The ability to know when and how to regulate conscious attention is an example of clinical decision making. The actual regulation of attention itself is a process that influences the outcome of a procedure, as well as the learning rates of surgical residents. If residents can recognize when their attention falters and a break would be beneficial, it will increase their learning efficiency. A good surgical curriculum ought to incorporate meta-cognition (learn residents how to learn efficiently).

Automatizing motor behavior is both a key and a threat to safe surgery. While in general, automatization of skills is crucial to reduce the sensitivity to stressors, it also hampers flexible task performance under unusual circumstances. As a consequence, the necessarily deviant execution of a standard operation introduces the risk of falling back into habitual execution. Knowing when and how to adjust is the result of years of experience, but the foundation for both fluency and flexibility should be fostered in surgical residents. Residents appreciate the inclusion of complex cases for decision making into the curriculum (Cook, Beckman, Thomas & Thompson, 2008). Learning about unique cases during training courses may lead to better understanding of individual variability in
patients and enhanced clinical decision making. In addition, flexibility can be achieved by interleaving training tasks (McDaniel, 2012) and introducing variable motor conditions of practice such as mirroring the image display (Jordan, Gallagher, McGuigan, McGlade & McClure, 2000).

During acquisition of new skills, the burden on the resident’s mental resources such as working memory is still high. This has implications for the way LS can be taught. That is, learning is hampered by teaching too many new skills at once or by presenting more information than the bare essentials for learning (van Merriënboer & Sweller, 2010). Since performing an entire laparoscopic operation would be too overwhelming for a novice, a trainee needs to demonstrate proficiency on different simpler training tasks first. As these basic training skills are practiced, these will become automatized over time, meaning that executing them will require less attention. As efficiency of basic surgical skills increases, more spare attention becomes available, which in turn allow the surgeon to handle the cognitive demands of a full operation (Gallagher & O’Sullivan, 2011). Thus, trained surgeons are increasingly able to detect anomalies, inhibit habitual actions, explore alternatives, and switch to an alternative approach, despite the intrinsic cognitive load of LS. This makes it less likely for a more trained surgeon to become overloaded when something goes wrong during an operation, as there will be enough attention available to deal with a possible emergency.

Additionally, a strong focus on career-long learning and deliberate practice (Ericsson, 2006) should be included in the curriculum. Our panel of surgeons reported that a sense of perfectionism is very important in their line of work and deliberate practice is characterized by a strong impulse to continue to master skills long after the point where proficiency has been reached during the period of training.

**Mental endurance**

Another important factor while performing surgery is the ability to focus on a task for extended periods of time, during monotone and routine steps as well as in cases of emergency. As it is important for a surgeon to develop the ability to stay calm and focused during emergencies, emotional stability is also an important psychological factor for predicting laparoscopic performance. The skill to stay emotionally centered during times of adversity in an operation is not limited to the degree of automation of basic surgical skills; it may also be influenced by other factors. Our panel of surgeons reported that emotional stability can be influenced by social, health and personality factors. If a surgeon is not well-rested, physically fit, or has an unresolved issue in his or her social life, this may have a detrimental effect on their performance. All of these may result in a compromised emotional stability in the operating room.
Also, residents should be taught about healthy posture, ergonomics (Van Det, Meijerink, Hoff, Totte, & Pierie, 2009; Wong, Smith & Crowe, 2010) and drawing healthy personal boundaries, in order to minimize fatigue, injuries or burn-out. Research has shown that performance on a surgical simulator deteriorates after working night shifts (Leff et al., 2008) and research on cognitive tasks has repeatedly shown that performance and especially cognitive control (Lorist, Boksem & Ridderinkhof, 2005) is impaired after inducement of mental fatigue. In order to ensure patient safety and to lower chances of burn-out, the surgical curriculum should emphasize the causes, symptoms and consequences of mental fatigue and encourage surgeons to develop healthy working schedules and conditions (Balch, Freischlag & Shanafelt, 2009).

**Social skills**

During advanced laparoscopic procedures four or more trocars are used, which means that an assistant is always required for handling the camera and usually a grasper instrument. Similarly, there are more OR team members who assist in preparing all the required instruments and materials. Hence, the ability to co-operate effectively with team members is essential, as complications may arise during surgery that requires quick team-work to respond to effectively. The primary surgeon should be able to instruct all the assisting staff successfully, even when these are inexperienced. Also, surgeons should be aware of hierarchies in the team (Undre, Sevdalis, Healey, Darzi & Vincent, 2007) and avoid blocking out valuable feedback from assisting team members.

Social skills can be trained by designing training formats that involve residents and co-assistants to practice skills in co-operation. An example of this is medical team training, in which the focus is placed on communication skills between surgeons, nurses and anesthesiologists based on principles of crew resource management (Awad et al., 2005). Also, learning rates can be improved by systematically implementing mutual feedback practices as a standard protocol after each procedure (London & Beatty, 1993). OR team members should also be educated regarding the nature of communication failures in the OR (Linhard et al., 2004) so that they can adjust their future behavior to avoid them.

**Technology skills**

According to our panel of surgeons, affinity with the hardware of laparoscopic surgery is another important skill. As one can imagine, being able to trouble-shoot a coagulation device or an ambiguous monitor image is highly preferred over calling in a technician during a surgical procedure. In this area there is potential for much improvement, as not all current forms of training familiarize students with technical possibilities (like contrast or shutter speed settings for example).
It is not uncommon for medical centers to purchase new technology without providing adequate training to the staff members using it. Training courses that teach the ins and outs of OR hardware would be of great benefit to the curriculum for surgical residents. E-learning courses on technology, using multimedia (Issa et al., 2011) and cognitive load (van Gog & Paas, 2008) principles can be used to train these skills.

**Conclusions**

In order to explore what constitutes expertise in LS, a CTA was conducted. The CTA yielded two results: (1) a procedural checklist for Laparoscopic Sigmoid Colon Resection with recommendations of difficulty levels for each step; and (2) a surgical skills profile that can be used as a guideline for creating a standardized curriculum for teaching residents in LS. It is desirable that each surgeon’s proficiency on important skills for LS can be charted and documented accurately in order to ensure valid self-efficacy of skill of surgeons, quality health care and transparency to the general public.

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