CHALLENGES IN TRAINING AND ASSESSMENT OF MINIMALLY INVASIVE SURGICAL SKILLS

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Abstract: Training and objective assessment of surgical competence receives more and more attention from society and medical communities, and is an ongoing research challenge. For obvious reasons of patient safety, ethics, and cost-effectiveness, there is a need to shift the training and assessment from the operating theatre to a simulated environment (e.g. skills lab). This paper presents the state of the art on training and assessment of surgical skills in minimally invasive surgery, and discusses remaining challenges.

1 INTRODUCTION

Minimally invasive surgery (MIS, 'keyhole surgery') has been introduced into surgery to the benefit of the patients. In contrast to conventional open surgery, MIS is performed through small (around 0.5 to 1 cm) incisions in the patient's body (Cuschieri, 1992). Through these incisions, special cannulas are inserted in order to allow the introduction of long, rigid instruments (e.g. scissors) into the patient's body. Visual feedback of the operating field is obtained by a small camera, which provides a two-dimensional (2D) image on a monitor. Figure 1 shows surgeons performing MIS.

Since MIS is performed through small incisions, patients experience less trauma than after an conventional open procedure. Moreover, MIS causes less postoperative pain and scaring. Patient' recovery time is faster, resulting in shorter hospitalization, and reduced incidence of post-surgical complications (e.g. adhesions, infections) (Cuschieri, 1992). For these reasons, MIS becomes progressively a common technique for major surgical procedures (e.g. in urology, gynaecology). The advantages of MIS, however, come with special demands on the surgeon, who needs to develop unique psychomotor skills that are different from those needed in the open procedures. These skills include a shift form a conventional 3D operating field to a 2D monitor display, reduced tactile feedback, distorted eye-hand coordination, alteration to the fulcrum effect, fewer degrees of freedom, judgment of distorted depth perception and spatial relationships (Wentink, 2003; Breedveld, 2000; den Boer 1999; Hanna, 1999; Hanna, 1998).

It is evident that proper education of future surgeons is crucial for patient safety. However, standardized training curricula and objective assessment methods are lacking. This paper presents the state of the art on training and assessment of MIS skills, and discusses remaining challenges.

Figure 1: The view of the operating room during MIS procedure. The patient is lying on the operating table in the supine position. The surgeons lead the operation from the left side of the patient. The camera operator stands next to the surgeon. Both the surgeon and the camera operator watch the operating area on a monitor (not presented in this picture).

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2 TRAINING OF MIS SKILLS

Mastering MIS skills requires repeated practice. Traditionally, residents learn MIS skills in a classic apprenticeship format with hands-on training in the operating room (OR). However, some MIS skills are difficult to be learnt in the OR because of its environment complexity. These skills include, e.g., psychomotor skills. Due to use of rigid instruments in a limited operating space, training of basic (psychomotor) skills can be done outside the OR.

Currently, training of MIS skills is being done in a traditional way (in the OR) and in a simulated environment (in the skills lab).

2.1 Traditional Training

Traditionally, surgical residents (trainees) learn their surgical skills while operating on patients under the supervision of an expert surgeon (Dankelman, 2005). First, they observe experienced surgeons performing several operations. After that, they participate in the operation more actively; they perform various basic techniques that they observed during the first phase of the training. Finally, they are taking a more independent role of a primary surgeon. Such way of learning is potentially unsafe for the patient. Moreover, it is not standardized, and results in very long learning curve (Moore, 2002). Besides, this kind of training is costly (Babineau, 2004; Bridges, 1999; Villegas, 2003).

Training of MIS skills takes also place on animal models and human cadavers (Giger, 2008; Nebot-Cegarra, 2004; Cundiff, 2001). The advantage of using human cadavers for training MIS skills is that they offer accurate anatomy. However, they lack of bleeding when vessels are damaged during training, and it is difficult to conserve the tissue of human cadavers. Animal models offer comparable physiological and tissue characteristics to those of humans (Waseda, 2005; Olinger, 1999; Crist, 1994; Bohm, 1994; Wolfe, 1993; Bailey, 1991). However, there are no animals whose anatomy is exact the same as that of humans. Moreover, animal models and human cadavers are costly and one-time usable. Besides, in several countries training on animals is prohibited.

2.2 Training in Skills Labs

Quality control and patient safety gained lately attention of health authorities and the public (Inspectie, 2007; Roberts, 2006; Ritchie, 2004; Satava, 2006). Therefore, there is a tendency to shift the training from the OR to a simulated environment.

Aggarwal et al. showed that training outside the OR – for example in skills labs – is efficient (Aggarwal, 2007). Thus, diverse training facilities are being developed (Kolkman, 2007; Halvorsen, 2005; Youngblood, 2005; Katz, 2005; Schijven, 2003). A box trainer and a virtual reality (VR) simulator are the most often used training facilities in the skills labs.

Typically, a box trainer (Fig. 2) mimics a part of a patient's body (e.g. abdomen) and the surrounding, as they are during real MIS. Box trainers allow to use conventional MIS instruments and equipment. In such a way, the residents are provided with a natural force feedback, which is equivalent to that obtained in the OR. The box can contain a variety of different synthetic inanimate models (e.g. simple physical objects such as pegs), synthetically produced organs, and animal parts (Waseda, 2005; Scott, 2000).

VR trainers (Fig. 3) allow a training based on the interaction with a computer-simulated environment. Currently, there are various VR trainers for MIS on the market (Halvorsen, 2005; Schijven, 2003). These trainers supply the user with objective feedback about his/her performance. Such feedback is motivating for the residents to learn (Aggarwal, 2004; Grantcharov, 2001). There are, however, only few VR trainers that are equipped with force feedback (Halvorsen, 2005; Schijven, 2003). This force feedback, however, is expensive and it differs from the one experienced in the OR.

In surgical trainers, and especially in VR trainers, there is a tendency to imitate reality as much as possible. It is, however, not known whether training on the high-fidelity trainers is the most effective one for learning basic MIS skills (e.g. eye-hand coordination) (Dankelman, 2005). In contrast to animal models and human cadavers, which allow training of various surgical skills, box trainers and VR trainers are mostly used to train psychomotor MIS skills only.

Figure 2: A box trainer used to train basic MIS skills.

Figure 3: Simendo – a virtual reality trainer developed by DelltaTech. (Courtesy of DelltaTech).

3 ASSESSMENT OF MIS SKILLS

Since MIS requires a lifelong learning, surgeons and surgical organizations (e.g. the Accreditation Council for Graduate Medical Education (ACGME), the Dutch Association for Endoscopic Surgery (NVEC), and the Dutch Health Care Inspectorate (IGZ)) are calling for assessment tools that can be used to credential surgeons as competent in MIS (Park, 2002; Roberts, 2006; Ritchie, 2004; Satava, 2006; Inspectie, 2007). Because MIS requires a large range of skills (e.g. motor skills, surgical judgment, team work, communication, fast acting, technical skills, cognitive knowledge), various objective assessment methods are needed to assess those skills.

A considerable amount of research has been conducted into assessment of MIS skills. Existing work can roughly be divided into three directions: i) Assessment based on performed operations; ii) Assessment of psychomotor MIS skills; iii) Task-specific checklists and global rating scores.

3.1 Performed Operations

One of the fundamental and most commonly used objective measure of surgical competence is the number of performed cases, which is easily quantifiable , and which indicates experience of a surgeon (Park, 2002). However, it does not represent the actual competence of the surgeon, since it is based on the measure of surgical experience only. It is also expected that different residents require different number of cases for gaining required surgical competence (Feldman, 2004).

Another easily quantifiable measures are the number of complications and the number of errors made (Mehrabi, 2006; Passerotti, 2008; Tang, 2005). Assessment of MIS competence based only on mortality and morbidity data is biased by the fact that each patient and case are always different and cannot be easily compared. Moreover, the identification of the causes and results of medical errors is complicated; it is difficult to identify errors and their effects from the progression of patients' underlying diseases, since different levels of sickness and fragility among patients.

3.2 Psychomotor MIS Skills

Psychomotor MIS skills are assessed by analyzing MIS instruments motion (Fig. 4) and/or applied forces to the tissue (Cotin, 2002; Moorthy, 2003; Van Sickle, 2005; Acosta, 2005; Cavallo, 2005; Chmarra, 2010; Cesanek, 2008; Allen, 2009; Cristancho, 2009). An example of typical MIS instrument motions is presented in Fig. 4. Variety of measures (parameters based on time-dependent 3D representation of the tip motions of the MIS instrument together with the rotation of the instrument around its axis) have been suggested. The most often used parameters are: time, path length, movement economy, depth perception, accuracy, deviation from the path, rotational orientation, and motion smoothness (Chmarra, 2010a).

Many academic hospitals are equipped with box trainers and VR trainers for the assessment of individual MIS skills (Feldman, 2006; Goff, 2000; Reznick, 1997; Dosis, 2005; Eriksen, 2005; Gallagher, 2001; Kundhal, 2009; Salgado, 2009). Such assessment is objective, but, similarly to the current assessment methods based on performed operations, it focuses on one aspect of competence.

3.3 Task-specific Checklists and Global Rating Scores

Evaluation methods based on task-specific checklists and global rating scores gained a lot of attention (McKinley, 2008; Moorthy, 2003). They include the Global Operative Assessment of Laparoscopic Skills (GOALS), and Objective Structured Assessment of Technical Skills (OSATS) (Moorthy, 2003; Goff, 2000; Gumbs, 2007; Chang, 2007; Pellen, 2009; Martin, 1997; Cuschieri, 1979; McKinley, 2008; Wincckel, 1994; Cohen, 1990). These methods assess more than one aspect of surgical competence, but it is difficult to judge surgical skills based on them, since there is no clear definition of the passing score that determines when a surgeon is competent at different moments of his/her career.

Task-specific checklists and global rating scores have been validated in the training environments. Their realization in the OR remains a challenge; it is

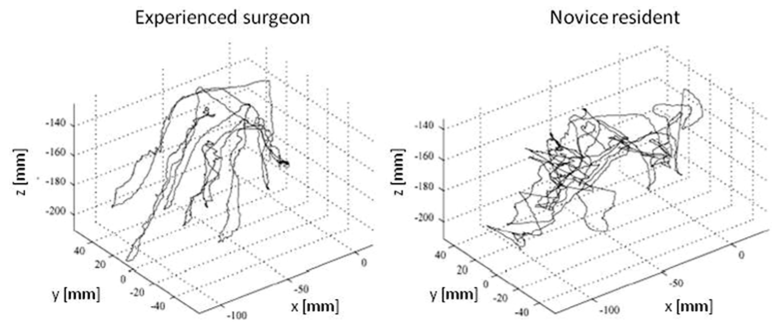

Figure 4: Typical instrument trajectories of an expert surgeon (left) and a novice (right) performing a positioning task. (Adapted from (Chmarra, 2010)).

not known how to assess the residents, because there is no clear description on when the various scores should be given. For example, two residents that obtained the same score in OSATS might have very different MIS skills. This is especially possible when assessing the first-year residents and the fifth-year residents; since the year of residency is often not taken into account. Another disadvantage of these methods is the fact that assessment of MIS skills is often done by surgical educators, who might be influenced by, for example, personal relationships.

4 CHALLENGES

Although various training and assessment methods of MIS skills exist, standardized training curricula and objective assessment methods are currently lacking. For example, the Dutch surgical residency program is very much regional; the residents follow a series of regionally organized courses and tutorials, which conclude with an assessment (Borel-Rinkes, 2008). The lack of national standardization of residency program results in confusion when comparing expertise of residents from different regions. Therefore, training and assessment methods in surgery should be standardized and formalized.

4.1 Training of MIS Skills

For obvious reasons of patient safety, ethics, and cost-effectiveness, training of MIS skills is being shifted from the OR to a simulated environment. A potential benefit of simulated environments is the possibility of introducing more uniformity across training programs at different medical centres. In a simulated environment, the training conditions are controlled exactly and objective assessment criteria can be defined.

At this point, there is a sense of disappointment about the results (e.g. efficiency, effectiveness) of current training programs. Although there have been few breakthrough attempts to improve the training of particular MIS skills, development of a proper curriculum to train competent surgeons remains a challenge.

To establish a reliable and valid training curriculum, it is necessary to find answers to four essential questions: *What* should be trained; *Where* should it be trained; *How* should it be trained; *When* should it be trained?

Currently, it is still not know ‘what’, ‘where’, ‘how’, and ‘when’ exactly should be trained. An attempt to identify essential abilities and skills that characterize surgical competence had been made by Satava et al. during a workshop, which was conducted ‘to establish a consensus on a baseline set of metrics from which future education, training, evaluation, and research in the technical aspects of surgical and procedural skills can be measured’ (Satava, 2003). The ability has been defined as ‘the natural state or condition of being capable, aptitude’, and the skill has been defined as ‘a developed proficiency or dexterity in some art, craft, or the like’ (Satava, 2003). Since the definitions provided by Satava should be seen as a first approximation at establishing a standard set of nomenclature, further studies are needed to either validate or refute these initial concepts. Furthermore, it is necessary to identify all the abilities and skills that characterize competent surgeons. After that, a redistribution of the surgical skills into sublevels (e.g. basic, intermediate, advance) should take place.

It is important to determine behavioural level at which the training is to be achieved, because it has been recognized that different behavioural characteristics should be learnt using different training methods (Wentink, 2003; Dankelman, 2007). Wentink proposed to devise surgeon’s behaviour using Rasmussen’s model of human behaviour, which distinguishes three levels: skill-based, rule-based, and knowledge-based levels

(Wentink, 2003; Rasmussen, 1983). Table 1 shows current training methods that are attributed to these three behavioural levels. Although currently available training methods are being used to train different behavioural characteristics, it is still necessary to identify essential surgical skills that characterize surgical competence.

Table 1: Levels of human behaviour in surgery.

Level of human behaviour	Training method
Skilled-based	Box trainer, VR trainer
Rule-based	Courses, literature, internet, VR trainer
Knowledge-based	Training in OR

VR – virtual reality; OR – operating room
Adapted from Dankelman (Dankelman, 2007)

There is a trend to imitate reality as much as possible in surgical trainers. To find out whether such high-fidelity trainers are the most effective ones when learning basic MIS skills, studies have been done to investigate whether those skills can also be acquired using a low-fidelity trainers, in which residents focus only on specific basic tasks. Fundamental knowledge on efficient and effective methods and tasks to train MIS skills, however, is still lacking.

It is not known at which stage of training which skills are learnt most effectively. Few studies investigated how long a separate training session should take and how long time between these sessions should be (Verdaasdonk, 2007; Duffy, 2005; Mackay, 2002). These studies showed that a common saying that ‘practice makes perfect’ is not the only determinant of motor MIS skills learning; the time that elapsed between two training sessions seems to have a significant influence as well. It has also been demonstrated that distributed training is superior to the massed training.

4.2 Assessment of MIS Skills

To establish a reliable assessment methods for MIS, it is necessary to find answers to four essential questions: *What* should be assessed; *Where* should it be assessed; *How* should it be assessed; *When* should it be assessed?

Any attempt to assess technical competence of a surgeon is difficult, because operative skill is a combination of a surgeon’s knowledge, judgment, and technical ability (Dankelman, 2005). Moreover, to be able to assess the operative skill, it is necessary to first measure that skill. Currently, there is no method that is able to objectively assess surgical competence based on data that includes: motion analysis, force measurements, errors, final result of operation, global assessment of performance, number of performed surgeries, complications, knowledge of anatomy, operational protocol, and knowledge of equipment. This is partly caused by the fact that not all the data mentioned above can easily be measured.

Since it is not known where various MIS skills should be trained, it is also not known (yet) where these skills should be assessed. It is, however, desirable to develop assessment methods that can be used independently of the training setup. Developing such methods is challenging, because factors such as patient safety and ergonomics in the OR play a critical role in designing these systems.

Assessment of technical competence of MIS surgeons is a largely ignored aspect in researches on patient safety, education in surgery, and MIS itself. Many researchers focus only on validation of new tasks and simulators for learning MIS skills (Vassiliou, 2006; van Sickle, 2005; Stefanidis, 2010), whereas only a few isolated studies have been found in the literature that introduce computer-aided methods to assess and classify the surgeons based on their technical competence (Cotin, 2002; Fraser, 2003; Allen, 2009; Cristiancho, 2009; Rosen, 2001; Chmarra, 2010). All these attempts focus only on manual dexterity of the surgeon, not taking into account other skills.

Another problem is how to determine a passing score, which defines when the surgeon is ‘good enough’. The research is usually limited to show that there is a correlation between the experience of a surgeon and the proposed assessment measure. Moreover, the existing methods assess competence mostly on one individual (isolated) MIS skill only. Few studies proposed methods to assess several skills (Goff, 2000; Gumbs, 2007; Martin, 1997; Mackay, 2003), but they combined these in a rather ad-hoc, subjective manner. Moreover, some of these methods were validated using data of experienced surgeons and novices only. It is not known whether these methods are able to distinguish between surgeons with a finer gradation in experience (e.g. expert and intermediate). Furthermore, none of these methods takes into account that certain skills (e.g. knowledge of procedure steps) can be compensated by other skills (e.g. good teamwork).

Assessment of technical competence of surgeons can be done either subjectively or objectively (Feldman, 2004). Most of the present training curricula use assessment methods that heavily rely on subjective assessment measures (Darzi, 1999; Martin, 1997; Moorthy, 2003). This should be changed, and objective assessment methods that are less likely to be biased by personal relationships, should be developed. There are two main advantages of introducing objective assessment methods: i) It is possible to compare surgical competence of various surgeons; ii) An objective assessment is more reliable than the subjective one. By consequence, residents will be more likely to accept objective feedback on their skills and constructively incorporate it in training.

It is difficult to say *when* assessment methods should be used; no reliable training curricula have been standardized nor widely used. It is, however, desirable to develop assessment methods that can be used at any time during training. Then it will be possible to improve training methods without necessity of developing new assessment methods. It is important to recognize that development of training curricula is closely associated with development of assessment methods. Once the MIS skills to be trained are known, it will become known which MIS skills have to be assessed. The same takes place the other way around; once the MIS skills to be assessed are known, it will become known which MIS skills have to be trained.

5 RECOMMENDATIONS

To develop reliable and correct training and assessment methods, few recommendations should be taken into account. First, it is necessary to 'follow the evidence of effectiveness'. Improved and/or new methods are likely to be more enthusiastically embraced and introduced when they are based on evidence of their effectiveness. Also, the results that indicate changes (e.g. improvement) in performance of the methods need to be measurable.

Patient safety introduces new knowledge into quality of performed surgery by way of disciplines such as human factors, sociology, organizational psychology, informatics. Therefore, development of training and assessment methods should be done in a multidisciplinary team.

After reliable and validated training curricula and assessment methods have been developed and implemented, hospitals can adapt their specialization areas to the strengths (and weaknesses) of their staff. Only then patients undergoing surgery will know that they are in 'good hands'.

6 CONCLUSIONS

Training and assessment of MIS skills is important from the patient safety point of view. To improve patient safety by better safeguarding the quality of surgical performance, a number of training and assessment methods have been developed and introduced in MIS. Training of MIS skills is currently done in the OR and in the skills labs, and can roughly be divided into assessment based on performed operations, assessment of psychomotor skills, and task-specific checklists and global rating scores. Establishment of reliable and valid training curricula and assessment methods is difficult, because fundamental questions of *what*, *where*, *how*, and *when* should be trained and assessed have not yet been answered. Studies should be conducted to find the answers to these questions and to develop appropriate training and assessment methods. Implementation of these methods in surgical training curricula should result in improvement of patient safety.

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