CHALLENGES IN TRAINING AND ASSESSMENT OF MINIMALLY INVASIVE SURGICAL SKILLS

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Abstract: Training and objective assessment of surgical competency 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’, i.e. laparoscopy) has been introduced into surgery to the benefit of the patients. In contrast to conventional open surgery, MIS is performed through few small (around 0.5 to 1 cm) incisions in the patient’s body [Cuschieri, 1992]. Through these incisions, special cannulas (trocars) are inserted in order to allow the introduction of long, rigid instruments (e.g. scissors, graspers) into the patient’s body. Visual feedback of the operating field is obtained by a small camera (endoscope), which provides a two-dimensional (2D) image on a monitor. Figure 1 shows two surgeons performing a MIS procedure in the operating room (OR).

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’s recovery time is faster, resulting in shorter hospitalization, and reduced incidence of post-surgical complications (such as adhesions and infections) [Cuschieri, 1992]. For these reasons, MIS becomes more and more a common technique for major surgical procedures (e.g. gynaecological, gastrointestinal, urological, and vascular surgeries).

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 from a conventional 3D operating field to a 2D monitor display, manipulation of long surgical instruments while adjusting for amplified tremor, 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; Bholat, 1999; 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 currently lacking. This paper presents the state of the art on training and assessment of surgical skills in MIS, and discusses remaining challenges.

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 OR. However, some MIS skills are difficult to be learnt in the OR because of its environment complexity. These skills include, for example, psychomotor skills. The fact that in MIS requires from the surgeon use of rigid instruments in a limited operating space, makes training of basic
Traditional Training

Traditionally, surgical residents (trainees) learn their surgical skills while operating on patients under the supervision of an expert surgeon [Dankelman, 2005]. In the first phase of the training, they observe experienced surgeons performing several operations. After that, trainees participate in the operation more actively; they perform various basic techniques that they have been observed during the first phase of the training. Finally, they are taking a more independent role of a primary surgeon. Such way of learning surgical skills 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]; for example, in the USA, the yearly cost of education of 1,014 general surgery residents in the OR is around €53 million [Villegas, 2003].

Training of MIS skills in the OR takes also place on animal models and human cadavers [Giger, 2008; Nebot-Cegarra, 2004; Cundiff, 2001]. The advantage of using human cadavers for training surgical skills is that they offer accurate anatomy. However, it is difficult to conserve the tissue of human cadavers. Moreover, there is lack of bleeding when vessels are damaged during training. These two shortcomings are the main reasons for using different training models in MIS. 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. The other disadvantages of using animal models and human cadavers for training purposes are costs and one-time usability. Moreover, 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 voor de gezondheidszorg, 2007; Roberts, 2006; Ritchie, 2004; Satava, 2006]. For that reason, and because of ethics and cost-effectiveness, 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]. For that reason, diverse training facilities are being developed [Kolkman, 2007; Halvorsen, 2005; Jakimowicz, 2005; Youngblood, 2005; Katz, 2005; Hance, 2005; Schijven, 2003; Anastakis, 1999; Rosser, 1998; Shapiro, 1996]. A box trainer and a virtual reality (VR) simulator are two examples of the most often used training facilities in the skills labs.

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

VR trainers (Fig. 3) allow a training, which is based on the interaction with a computer-simulated environment. Currently, there are various VR trainers for learning MIS skills on the market [Halvorsen, 2005; Schijven, 2003]. These trainers have the advantage over box trainers, because they supply the user with objective feedback about his/her performance. Such feedback is motivating for the residents to learn [Aggarwal, 2004; Grantcharov, 2001; Darzi, 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 that the surgeons experiences when using the real MIS instruments during operations.

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]. Currently, there is a variety of box trainers and VR trainers available on the market. 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.

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 voor de gezondheidszorg, 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:

- Assessment based on performed operations;
- Assessment of psychomotor MIS skills;
- Task-specific checklists and global rating scores.

3.1 Assessment Based on Performed Operations

One of the fundamental and most commonly used objective measure of surgical competency is the number of performed cases, which indicates experience of a surgeon [Park, 2002]. It is also an easily quantifiable measure. This measure, however, does not represent the actual competency of the surgeon, since it is based on the measure of surgical experience only, and because it not known how many performance cases are required for competency. It is also expected that different residents require different number of cases for gaining required surgical competency [Feldman, 2004].

Another evaluation measures that are easily quantifiable are the number of complications and the number of errors made [Moore, 1995; Morgenstern, 1995; Lekawa, 1995; Mehrabi, 2006; Passerotti, 2008; Bann, 2003; Tang, 2005]. An assessment of surgical competency based on mortality and morbidity data only does not provide correct information on the real surgical competency. This is mostly caused by the fact that each patient and each case is always different and cannot be easily
compared. Moreover, the identification of the causes and results of medical errors can be far more complicated than an investigation of accidents in other settings; it is difficult to identify both errors and their effects from the progression of patients’ underlying diseases, since there are different levels of sickness and fragility among patients.

3.2 Assessment of Psychomotor MIS Skills

Psychomotor MIS skills are assessed by analyzing MIS instruments motion (Fig. 4) and/or applied forces to the tissue [Cotin, 2002; Moorothy, 2003; Van Sickle, 2005; Acosta, 2005; Cavallo, 2005; Strom, 2004; Smith, 2001; Chmarra, 2010; Cesanek, 2008; Allen, 2009; Datta, 2001; Cristancho, 2009]. An example of typical MIS instrument movements of an experienced surgeon and a novice resident performing the same positioning task 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 to assess psychomotor skills 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 (mostly psychomotor 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 only on one aspect of competency.

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; Moorothy, 2003]. These methods include the Global Operative Assessment of Laparoscopic Skills (GOALS), Objective Structured Assessment of Technical Skills (OSATS), Multiple Objective Measures of Skill (MOMS), Objective Structured Clinical Human Reliability Assessment (OCHRA) [Tang, 2005; Moorothy, 2003; Goff, 2001; Vassiliou, 2005; Gumbs, 2007; Chang, 2007; Aggarwal, 2008; Pellen, 2009; Martin, 1997; Mackay, 2003; Cuschieri, 1979; McKinley, 2008; Winckel, 1994; Cohen, 1990; Joice, 1998; Tang, 2004]. These methods assess more than one aspect of surgical competency, but it is difficult to judge surgical skills based on these methods, since there is no clear definition of the passing scores that determine 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. Implementation of these methods in the OR remains a challenge; it is still not known how to assess the residents, because there is no clear definition 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 an educator has to judge on skills of the first-year residents and the fifth-year residents, because during assessment, the year of residency is often not taken into account. Another disadvantage of currently used checklists

![Figure 4: Typical instrument trajectories of an expert surgeon (left) and a novice (right) performing a positioning task. (Adapted from [Chmarra, 2010].)](image)
and rating scores 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 et al. should be seen as a first approximation at establishing a standard set of nomenclature, further studies need to be done to either validate or refute these initial concepts and standards. 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 (appropriate) 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>
<thead>
<tr>
<th>Level of human behaviour</th>
<th>Training method</th>
</tr>
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<tbody>
<tr>
<td>Skilled-based</td>
<td>Box trainer, VR trainer</td>
</tr>
<tr>
<td>Rule-based</td>
<td>Courses, literature, internet, VR trainer</td>
</tr>
<tr>
<td>Knowledge-based</td>
<td>Training in OR</td>
</tr>
</tbody>
</table>
VR – virtual reality; OR – operating room

Adapted from Dankelman [Dankelman, 2007]

As mentioned above, there is a trend in surgical trainers to imitate reality as much as possible. 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. Such studies are mostly done to compare the low-fidelity trainers that are affordable for most training hospitals with much more complex and expensive high-fidelity trainers, which are affordable for specialized skills labs only.
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 to 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, in order 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 competency based on data that includes: motion analysis, force measurements, errors (e.g. missed targets, tissue tearing, bleeding, organ perforation, burning wrong tissue, recovery from error), final result of operation, global assessment of performance, data about patient (e.g. BMI, age), number of performed surgeries, number of surgeries performed per week, number of 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; Maithel, 2006; 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 (e.g. motion analysis parameters, applied forces, and accuracy), not taking into account other surgical skills.

Another problem not addressed in most of the literature 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 competency mostly on one individual (isolated) MIS skill only (e.g. psychomotor skill, teamwork). MIS, however, requires a broad range of skills. Few studies proposed methods to assess several skills [Goff, 2000; Gumbs, 2007; Martin, 1997; Mackay, 2003; Tang, 2004; Tang, 2006], but they combined these in a rather ad-hoc, subjective manner. Moreover, some of the proposed 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 competency 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; Wanzel, 2002; 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:

- It is possible to compare surgical competency of various surgeons;
- An objective assessment is more reliable than the subjective one. By consequence, residents are 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, since 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 and introduce reliable and correct training and assessment methods, few recommendations should be taken into account. First of all, it is necessary to ‘follow the evidence of effectiveness’. Improved and/or new training and assessment 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 of MIS skills should be done in a multidisciplinary team. Development of the methods will require funding and time to yield meaningful research and results.

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. Assessment of MIS skills 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 by better safeguarding the quality of surgical performance. Once training curricula and assessment methods are standardized, it is expected that patients undergoing MIS will know that they are in ‘good hands’.

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