Guest editorial

Image-guided surgical simulation—a proven improvement

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New technology and human factors

The minimally invasive surgical revolution has changed the way surgery is practiced. Image-guided interventions in many fields, e.g. laparoscopic surgery, arthroscopic surgery, natural orifice endoscopy and percutaneous intravascular stenting are rapidly becoming commonplace. The technique requires perceptual, visuospatial and psychomotor skills not previously addressed in medical education and training. Although minimally invasive surgery provides considerable advantages to the patient in many cases, it has imposed significant difficulties on the surgeon and impact on outcomes (Robinson et al. 2001). Until now, the surgical difficulties have not been sufficiently addressed and understood by key groups such as designers and manufacturers of devices, and educators and trainers in surgery. Surgical training will require a fundamental revision to ensure that surgeons are competent in carrying out the new procedures (Wickham 1994).

Advanced simulation technology

Simulation is best known in the world of aviation where, for over half a century, it has been included routinely in the continuous training and recertification of pilots. The world of medicine has much to learn from the safety culture in aviation (Helmreich and Merritt 1998). Medical simulators have rapidly evolved from primitive mannequins into machines with inherent technology and computer power capable of creating realistic physiological and patient scenarios as well as metrics. Several procedural or partial-task trainers are now available with high-fidelity computer graphics of relevant anatomy, including deformable tissues and appropriate physiological reactions. These are connected to bimanual or bimanual and pedal devices, some with haptics (i.e. tactile feedback), which allow a multitude of tasks ranging from practice of endoscopic procedures to suture placement. Advanced medical simulation is not a standalone technique. It must be part of a modern curriculum. Current virtual reality simulators for image-guided surgery include the Minimally Invasive Surgical Trainer for basic eye-hand-foot coordination (Procedicus MIST, Mentice, Göteborg, Sweden; see Figure 1). This simulator is currently the gold standard, since it has been evaluated extensively (e.g. Seymour et al. 2002, Gallagher et al. 2001, 2003, Ström et al. 2003a, b). Full procedural simulators also exist, both for full-scale patient simulation (Human Patient Simulator METI, Fl, USA; Figure 2) and with anatomy and physiology associated with interventions such as e.g. arthroscopy (Procedicus VA, Mentice, Göteborg, Sweden), bronchoscopy (Accutouch, Immersion, USA), cystoscopy (UroMentor, Simbionix, Ohio, USA), transurethral prostate resection (UroMentor, Simbionix, Ohio, USA), gastroscopy (GI Mentor Simbionix, Ohio, USA), colonoscopy (GI Mentor Simbionix, Ohio, USA or Accut-

Figure 1. Gold standard simulator (minimally invasive surgical trainer) for basic eye-hand-foot coordination.

ouch, Immersion, USA), gastroscopy (GI Mentor Simbionix, Ohio, USA; Figure 3), intravascular procedures and coronary stent or cardiac lead placement (Procedicus VIST, Mentice, Göteborg, Sweden), and laparoscopic surgery (Procedicus Abdomen, Mentice, Göteborg, Sweden; LapSim, Surgical Science, Göteborg, Sweden; LapMentor, Simbionix, Ohio, USA). The role of these simulators in assessment and training of surgeons is now being evaluated. All of these simulators have performance metrics, and validation of psychometric and scientific standards is in progress (Dawson et al. 2000, Gallagher et al. 2001, 2003, Ahlberg et al. 2002, Seymour et al. 2002, Gallagher and Smith 2003, Ström et al. 2003a, b). The level of difficulty can be varied in each simulator, and the degree of difficulty also varies between the different simulators. For example, medical students were surprised by the difficulties in manoeuvring a virtual arthroscope and probe inside the knee with its narrow space (Figure 4) compared to basic manoevering in laparoscopy, and also compared to basic virtual shoulder arthroscopy (Ström et al. 2003b).

Figure 2. Human patient simulator for full-scale patient simulation.

Figure 3. Simulator for gastroscopy.

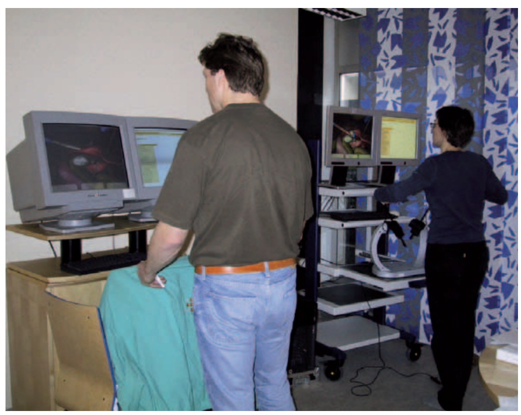

Figure 4. Virtual arthroscopy simulator.

The effect of advanced image-guided surgical simulation on performance

An advanced simulator for image-guided surgery can differentiate between novices and experienced

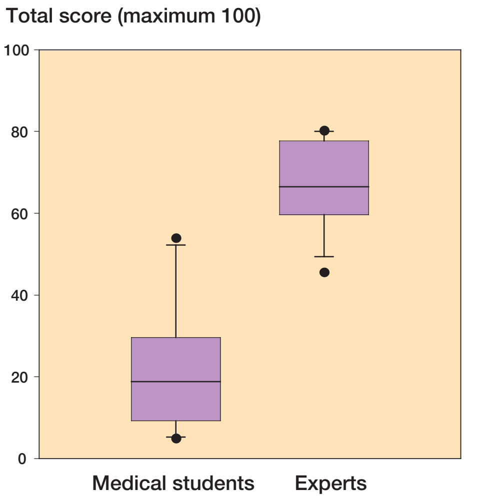

Figure 5. Total score in image-guided surgical simulation in medical students and experts in image-guided surgery (Procedicus KSA total score; $p < 0.001$; t-test).

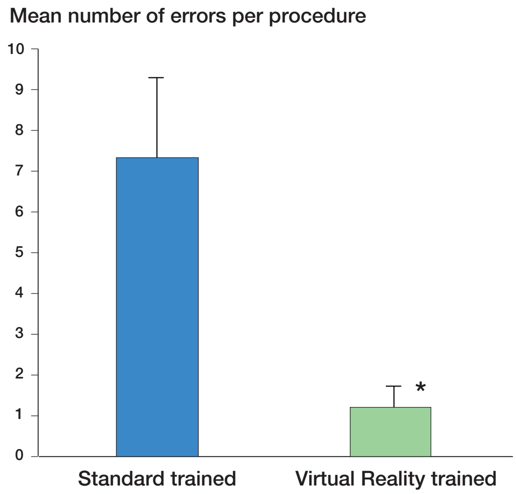

Figure 6. Error occurrence in simulator-trained (virtual reality) and conventionally trained surgical residents performing a videotaped laparoscopic cholecystectomy (Seymour et al. 2002).

surgeons (Figure 5) (Taffinder et al. 1998, Chaudry et al. 1999, Gallagher et al. 2001). Seymour et al. (2002) have also demonstrated that skills from training in a simulator for eye-hand coordination are transferred over to the real clinical situation: surgical residents who completed virtual reality training in a simulator performed 6 times fewer errors and operated 30% faster than a matched control group completing traditional training (Figure 6). Recently, Gallagher et al. (2003) demonstrated that occasionally, experienced surgeons performed 20 standard deviations from the mean of a cohort in a minimally invasive surgical simulator. These findings clearly raise the question of basic quality control measurement of surgeons for eye, hand, and foot coordination by validated simulators.

The three fundamentals for successful integration of simulation into medical training are curriculum, metrics and validation. The use of advanced virtual reality medical simulators is important (Issenberg et al. 1999, Rystedt 1999, Gorman et al. 2000, Haluck and Krummel 2000). Their use will reduce educational costs (Bridges and Dimond 1999), circumvent the ethical issues associated with training new surgeons on animal specimens, and improve both outcome of surgery and patient safety (Berwick and Leape 1999, Dawson et al. 2000). Recent studies have shown that training of basic visuospatial skills dramatically reduces error in endoscopic surgery (Gallagher et al. 2003, Ritter et al. 2003, Seymour et al. 2003).

Abilities and human factors

Wanzel et al. (2002) concluded that visuospatial ability is related to results in complex open surgery and therefore could potentially be used in resident selection, career counselling, and training. Much of the routine technology for the Operating Room of the Future already exists (robotic surgery, virtual reality, and telemedicine). However, optimal functioning of these advanced technologies has new implications for education and training of the practitioners (Gallagher and Smith 2003). It must be demonstrated unequivocally that these technologies have positive benefits for patients in terms of better outcome, and for surgeons in terms of abilities and the usefulness of new technical solutions, taking human factors into account (Gallagher and Smith 2003).

New tools for safe basic training

The demands of society for greater accountability and objectivity in the medical profession, and the profession's need for uniformity in training, are major driving forces for a new safety culture in high-technological medical education and training. Today, there is also pressure for cost effectiveness in training and a need to respond to the reduction in exposure of the trainee to patients. These pressures are forcing surgeons to invoke new technologies to support the competence and integrity of the profession. Features of these technologies include increased capabilities of computer software, allowing advanced graphics in human anatomy and physiology, advances in psychology and education which can affect the selection, training and testing of medical personnel, and advances in haptic engineering which enable the virtual environment to relate to the sensory input of the human hand. All of this is now being scrutinized against the ethical issue of killing animals for technical training, and the ethical question of whether patients should be subjected to even closely supervised training without the surgeon ever having passed a minimum criterion level regarding visuospatial abilities.

It is important for the medical profession to standardize basic skills accreditation in different fields to provide services at or above a preset minimum level regarding standard of performance. To use visuospatial tests in order to control for differences in visuospatial ability between groups, is already a common method in medical simulator studies (Ström et al. 2003b). Better understanding of the relationship between pure visuospatial abilities and specific surgical tasks may lead to better teaching methods. It will then be possible to train on specific individual tasks to optimize the overall performance of each surgeon.

We consider that part of the solution lies in changes to the physical environment in which we work—examining the role that equipment plays in our routines. Another element of error prevention lies in our daily routines and in the dual meaning of the word ‘practice’. Every experienced medical practitioner knows that he/she becomes better with time; that practice really does improve performance. Likewise, the notion that mistakes are often prevented by skill is well known. A modern curriculum must incorporate the simulator and, ideally, cognitive and technical task analysis should be performed by end-users before the simulator is created. It is not acceptable educational practice to acquire a simulator and point novices to it with instructions “to practice”. Simulators are tools to be integrated into a curriculum with clear skill acquisition goals. Skill transfer and skill generalization must be addressed (Champion and Gallagher 2003). Skill transfer occurs when the simulated task relates directly to the operative task. An example of this is dissection of the gall bladder from the liver with a cautery L hook (Seymour et al. 2002). Skill generalization means a broader range of generic skills, for instance endoscopic psychomotor skills in order to improve operative task performance (Champion and Gallagher 2003).

It is important to introduce the elements of correct behaviour and good habits early in the training of surgeons, as bad habits and negative stereotypes develop quickly (Horder 1996). Optimally, simulators as part of a training curriculum should be introduced already in the undergraduate medical education before prejudice and fear of lack of technical skills develop. It is important to bear in mind that simulators must be used wisely in order to avoid negative training, i.e. training that establishes and reinforces bad habits. This is imperative since it is easy to acquire a bad habit that, once learned, is very difficult to abandon (Martin and Bateson 1986). On a more positive note, simulators have an extraordinarily powerful potential for training at the margins of practice, since they can allow one to make errors and to learn from such errors in a non-threatening fashion, without risk to the patient. Furthermore, it should be appreciated that simulators not only provide training in technical manoeuvres; they can also be used to teach decision making and judgement.

Selection of suitable subjects with simulators?

The primary goal when incorporating advanced simulators for image-guided surgery should not be to deselect subjects. Professionalism and clinical skills consist of a variety of entities quite apart from pure manual skills (e.g. cognitive skills, theoretical knowledge, critical thinking, decision making, visuospatial skills, psychomotor skills and psychosocial skills). Evidently, the use of advanced simulators for image-guided intervention is a modern means of optimizing training of complex tasks. However, simulators with embedded metrics and tutoring may help medical students to decide whether to be (or not to be) a surgeon. They also permit accreditation based on established objective performance criteria, rather than by checklists, written and oral examinations and time in a post—which are still used to define specialists. Simulators will also allow a subject to monitor the acquisition of skills against national or international benchmarks. Criterion-based cognitive and technical skills assessment may ultimately become part of professional certification. The American College of Surgeons has identified simulation as an important factor in ensuring patient safety, together with evidence-based practice and peer review (Healy 2002). The existing data suggest that image-guided surgical simulation is a proven improvement in high-technological healthcare education.

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