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Virtual Reality Simulation: A Valuable Adjunct to Surgical Training

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1. Introduction

Clinical experience has shown that surgeons need to perform a certain number of procedures to gain competency and continue performing a certain number of procedures to maintain these skills (1,2). More and more, it is becoming increasingly difficult to obtain an adequate amount of live operating, even for fully trained doctors. Reasons for this include reduced working hours, an increasingly consultant-led service, a better-educated patient body, with an increasing focus on their safety and rights. Previously junior doctors had ample opportunity to operate independently with indirect supervision from a more senior colleague; unfortunately this is becoming less common (3). Healthcare resources are becoming increasingly scarce, which adversely affects the amount of theatre time that a trainee has access to (4). The European Working Time Directive led to a change in the working pattern of junior doctors in the UK with significant reduction in available hours and a greater proportion of their time spent in service provision. Furthermore, certain major operations are being replaced by less radical options such as a surgical/medical endometrial ablation replacing hysterectomy. Or alternatively, traditional surgery is being replaced by more sophisticated techniques, which experienced surgeons have to master prior to junior trainees having the opportunity to develop their skills. One example is robotic surgery and its incorporation into gynaecological minimal access surgery.

Surgical skills were traditionally acquired by practising on 'live' patients, but it is apparent that the operating room is not the ideal learning environment. Trainees are generally less time efficient than experienced surgeons with implications for theatre management and healthcare budget. The complication rate has been found to correlate with the experience of the surgeon (5-10) which is concerning with the ever-increasing emphasis on litigation. As surgeons become more experienced in laparoscopic surgery, the complication rate decreases and their ability to deal with complications in keeping

with the minimal access approach increases (11). Even for experienced surgeons the learning curve for advanced laparoscopic procedures is fifty cases; total operative time for hysterectomies stabilised at approximately 95 minutes after fifty cases (12). The hypothesis that is being addressed is that training on a laparoscopic simulator shortens the learning curve, which has stimulated the development of simulation systems and their implementation into clinical practice.

2. Simulation in other professions

At present there is extensive knowledge about how to teach technical skills in professions where accurate and reliable performance is critical. High performance musicians and athletes on average invest 10 years of intense practice before they are considered experts (13). Surgeons, by comparison, are currently expected to 'perform' to a competent level without first practicing in a low-risk environment. Many doctors recall a familiar adage 'see one, do one, teach one'. Simulation-based training using flight simulators has been mandatory in the United States aviation industry since 1955 (14). All commercial and military pilots must train and be certified on a simulator before actual flight. Departments of Anesthesiology have applied principles similar to those used in pilot training with over 30 years of history in simulation-based training (15).

3. Physical simulation

Simulation can be described as an exercise that reproduces or emulates, under artificial conditions, components of surgical procedures that are likely to occur under normal circumstances (16). In the area of laparoscopic surgery, simulators fall into 2 broad categories: computer based simulators, in which the task is performed in a 'virtual' environment (17) and video-based simulators, in which the task is generally performed in a trainer box under videoscopic guidance. In the virtual reality simulator (VR), the student performs 'virtual' tasks in a computer-generated environment that allows sensory interaction. Unlike the box trainer, VR provides no tactile feedback (haptics). However, innate ability can be evaluated using computer-derived metrics; different aspects of performance can be analyzed at a later date (18). The main disadvantages of the VR simulator are the lack of portability, high start-up costs and ongoing maintenance. Physical simulators are widely available and include bench simulation, live animal model and human cadavers (19). The video or 'box' trainer (VT) is a basic training simulator in which users perform tasks with 'real' laparoscopic instruments under videoscopic guidance. Unlike the VR simulator, it is inexpensive, reproducible and provides 'haptic' feedback. Hybrid simulators combine both attributes of VT and VR simulators. Normally the hybrid simulation system incorporates a mannequin linked to a computer programme that provides visual images or feedback. This facilitates the creation of a realistic clinical environment where trainees can work as a team and respond to clinical situations.

4. Haptic technology

Haptic technology, or haptics, is a tactile feedback system that generates tactile sensations to the user. This mechanical stimulation can be used to assist in the creation of virtual objects in a computer simulation, to control such virtual objects, and to enhance the remote control of machines and devices (telerobotics). Haptics has been incorporated into VR simulators without compelling evidence that it adds benefit to training. This is significant because this technology costs a considerable amount of money in both the initial purchase of the equipment and the ongoing maintenance. Thompson et al (20) investigated the incorporation of haptics in virtual reality laparoscopic cholecystectomy training. Thirty-three laparoscopic novice students were placed into one of three groups: control, haptics-trained, or non-haptics trained group. The study found that haptics does not improve the efficiency or effectiveness of VR laparoscopic surgery training. They concluded that haptics should not be included routinely in surgery training. The strength of the study was weakened by the high attrition rate; more than 50% in the study groups but less than 10% in the control group. This was attributed to the time commitment involved and the technical difficulty encountered by the participants. Although the incorporation of haptic technology increases the financial burden, no clear benefit with respect to training has been demonstrated (21,22). A systemic review (23) reported that although the majority of results show a positive advantage from haptic technology in MIS, interarticle consensus is neither absolute nor firm. Furthermore, the general level of evidence was poor (level 3b). More objective study results based on valid end parameters need to be obtained to reliably report the value of haptic feedback.

5. Future developments

Telesurgery is a developing field for potential use in remote sites such as the battlefield and in space, once technology improves. Telesurgery will enable surgeons to operate on patients who are physically separated from them. Most of the research to date has been carried out on animals. A prototype telemanipulator has been used successfully to perform basic vascular and urological procedures in pigs (24). At present there is no role for the use of telesurgery in surgical practice due to the reliance on telephone line technology and telephone companies. Telesurgery will only become possible when surgery becomes digital with failsafe communications (25).

Another exciting area in laparoscopic surgery is the emergence of robotic assisted operations. The application of robotics provides surgeons with a remarkable three-dimensional image. The surgeon is able to sit comfortably and perform operations without the risk of soft tissue strain and fatigue, a common occurrence in laparoscopic surgeons who regularly partake in complex and prolonged operations. The consoles and instruments are very sensitive to movement and the awkward motions of minimally invasive procedures can be translated into natural hand motions from a surgical workstation. However these machines are extremely expensive to buy and require a large amount of space to operate because of the sheer size of the robotic arms. Entire operating theatres are taken up by the

enormity of these robots. There are also some practical limitations, including not being able to change the position of your port sites once the operation has started.

These developments in surgical technology will influence and develop current practice. As these new technologies are validated there will be a new richness to surgery that will require even more surgical skills and training. The practice of surgery will not be replaced but will change and evolve. As a surgeon, the challenge is to be aware of the opportunities, rigorously evaluate the technologies and be willing to change if evidence-based outcomes demonstrate a clear benefit for the patient (26)

6. Simulation in surgery

Operative skill is a mixture of knowledge, clinical judgment and technical skill. As traditional surgical techniques are being replaced by minimal access approaches, surgeons in training need to adapt to this new technology. Minimal access surgery presents new challenges to the trainee surgeon such as operating in a 2-dimensional environment, reduced tactile feedback, new instrumentation and the 'fulcrum' effect (27). Fortunately minimal access surgery is amenable to simulator training and the benefits of simulator training are numerous. Laparoscopic simulators provide a safe, protected, unhurried environment where trainees can operate independently. Tasks can be presented consistently allowing the development of laparoscopic skills irrespective of prior surgical experience, sex or age (28). Laparoscopic skill can be measured on a simulator and performance improved with practice (most of this improvement was a result of speed rather than accuracy). The effect of repetition on performance overall and for each task individually was highly significant, confirming the simulator model as a valuable practice tool (29).

7. Acceptance of surgical simulation

Simulation-based training is becoming widely available to help trainees develop sound technical skills before they practice on real patients. Although it provides a nonthreatening, controlled environment, it is not being widely accepted into current clinical practice. An important issue is how to create optimal conditions for integration of simulators into the training curriculum. The willingness of twenty-one surgical residents to train on a voluntary basis was surveyed. Access was unrestricted for a period of 4 months, following which a competitive element was introduced. Free unlimited access to a VR simulator, without any form of obligation or assessment, did not motivate surgical residents to use the simulator; introducing a competitive element had only a marginal effect. The majority of residents (86%) stated that 'lack of time due to high working pressure' was the most important reason for not using the simulator. Therefore, the acquisition of expensive devices is probably only effective if it becomes a compulsory part of the training curriculum (30). Recent studies stated that trainees prefer video box trainers to virtual reality, citing better visualization and tactile feedback that made video box trainers more realistic; it should be the first choice if only one trainer was allowed (31,32).

8. The evidence for computer-based simulation

Virtual reality simulation allows trainees to interact efficiently with three-dimensional, deformable, computerized databases in real-time, using their natural senses and skills (33). Their application is more evident in laparoscopic as opposed to 'open' surgery. Surgical simulation provides the appropriate environment where very complex surgical procedures can be broken down into several simple tasks with the opportunity for mass and deliberate practice. Multiple repetitions of a skill, such as laparoscopic suturing, are needed to acquire the necessary hand eye coordination and muscle memory. There is evidence that computer-based surgical simulation leads to improved performance in complex laparoscopic tasks like suturing (34). This leads to decreased task completion time and increased accuracy. An important advantage of computer-based simulation is its ability to generate out-put data which reflects competence of the trainee and can be used for performance assessment.

A meta-analysis by Haque and Srinivasan (35) analysed 16 prospective and randomized studies for the effectiveness of VR simulation. The author's goal was to evaluate the effectiveness of surgical simulation and to assess the validity of current simulation. The authors found that surgical simulation was not superior to standard 'Heilsteidan' training methods. Their work suggested that training in VR simulators lessens the time taken for a given surgical task and clearly differentiates between experienced and naïve surgeons. However the authors cited several systematic problems as potential reasons for the failure of studies to show significant advantages of simulation technology including small sample sizes, low statistical power, lack of accepted validity measures, non blinded assessors and poor funding.

A recent Cochrane Review (36) of randomized, controlled trials investigated the effectiveness of simulation-based training interventions. The authors felt that until standards are adopted for establishing and reporting performance evidence from rigorous psychometric assessment instruments, the literature examining the efficacy of simulation-based surgical training will be limited. Although research of higher methodological quality is needed, the evidence would suggest that VR training improves standard surgical training with preliminary data supporting the concept that these skills translate into more effective operating room performance (17). A study by Larsen et al (37) showed that criterion based procedural training using a virtual reality simulator can help compensate for reduced working hours by bringing trainees to a higher level of performance more quickly.

9. Computer-based versus video box trainers

There is currently no universally accepted or recommended single model for laparoscopic simulation (38). Video box trainers seemed to be equally efficient as virtual reality simulators (39,40). In the systemic review by Sutherland et al (41), including 30 RCTs (760 participants), individuals trained in VR performed better than no training. The effect was

less marked when compared with standard laparoscopic training; VR vs. VT no conclusive results. The Cochrane review by Gurusamy et al (42) that included 23 trials concluded that VR training can supplement standard laparoscopic training, and it is as least as effective as VT.

Youngblood et al (43) randomly assigned 46 surgically naïve medical students to three groups: tower training, VR (Lapsim) and the control group. The time and accuracy of three laparoscopic tasks in a living animal model were assessed; four experienced surgeons evaluated performance. Trained groups performed better compared to the control group but not for all outcomes measured. The authors reported that surgically naïve medical students (n=46) trained on a VR simulator performed better on three of seven outcome measures during live surgical tasks in a porcine model as compared with those trained with a box trainer (time, accuracy and global score; $p<0.05$).

Although training on both VR and VT effectively improves psychomotor skills, a trend towards greater improvement was found with the MIST VR that was transferable to the OR. Fifty surgical trainees were randomized to either a VT or VR trainer. The effect of task training was assessed via a pre- and post-test assessment on VT, VR and intraoperative assessment during laparoscopic cholecystectomy. Although both groups improved, operative performance improved only in the VR group ($p<0.05$). Furthermore, the VR group performed significantly better when tested on VT tasks suggesting that skills developed on one system appear to be transferable to the other modality (32).

The systemic review by Gurusamy et al (36) examined whether virtual reality training can supplement or replace conventional laparoscopic surgical training in trainees with little or no experience. Results were reported separately for trainees with no laparoscopic experience and for those with limited experience. The review included 23 randomised, controlled trials (612 participants). Four trials compared VR with VT, 12 trials compared VR with standard laparoscopic training (SLT), four trials compared VR, VT and no training and three trials compared different methods of VR training. Generation of allocation sequence, allocation concealment, blinding and follow-up were examined. Three trials that had adequate methodological quality in all four components were considered to have a low risk of bias. Five different parameters were examined in the VR vs. SLT group (limited laparoscopic experience) namely patient outcome, operating time, error score, composite score and economy of movements. Operating time was statistically significantly shorter in the VR group in two trials; five trials reported a statistically significantly lower error score in the VR group. Although there were methodological flaws with the majority of trials included, the author reported that virtual reality decreased time, decreased errors and increased accuracy compared with no training. The authors concluded that the advantages of VR over VT are not as evident as for VR over standard training. Virtual reality training should supplement standard laparoscopic surgical training. Common problems in studies to date include lack of universally agreed metrics, a variety of simulators, differing skill levels of participants, and small sample sizes. Despite this, most studies are in keeping with the positive impact of laparoscopic surgical simulation.

An important consideration in our era of financial restraints is the consideration of cost of surgical simulation. The hospital administration needs to be convinced that simulation will be cost effective before funding is made available. The main consideration is whether the low-tech, inexpensive video box trainer is as good as the considerably more expensive virtual reality trainer with the ability to provide haptic feedback for continual assessment? In a study performed at the University of Toronto (44), urology trainees were randomized to three types of training to extract a urethral stone. The first group received detailed instructions only, the second group was trained in a high fidelity virtual reality model and the third group was trained on a low-tech model using Styrofoam cups and straws placed in the anatomical orientation of the normal bladder. All participants were subsequently tested on the VR fidelity video endoscopic trainer. The two groups with hands-on teaching on either trainer did better than the group who received instructions only. Training in the low fidelity model conferred as much benefit as training on the high fidelity model. This evidence was backed up by a study performed by Goff et al (45) with respect to assessment of hysteroscopy skills; assessment in the low-tech trainer was actually better than assessment in the expensive virtual reality trainer.

10. Transfer of training

The main goal of any training method is the positive transfer of skills to the operating room. So does laparoscopic simulator training translate into improved operative performance? High-grade evidence on the effect of virtual reality simulator training on real operation performance was limited until now. The evidence that simulation training actually translates to improved surgical skills in the operating room is increasing and several studies now prove that laboratory based training improves surgical skills. Two studies compared simulator training and concurrent operating room performance in the porcine model (46,47). Grantcharov et al (46) assessed fourteen residents on an animal model with pre- and post-training on a VR model. The study demonstrated that in vitro scores for VR tasks are comparable to performance during operations on living animals. Although sample size was small and assessors were not 'blinded', the study suggests that the computer model shows promise as an aid to evaluate and assess trainee surgeons. Good correlation was found between performance in MIST-VR and cholecystectomy. A later study by Seymour et al (48) was one of the first studies to demonstrate a significant improvement in OR performance of residents. In a prospective, randomised, blinded study, sixteen surgical residents were randomized to VR training plus standard laparoscopic training (SLT) or control (SLT only). The training goal for the residents in the VR group was to perform as well as four experienced surgeons on the 'manipulate and diathermy' task on two consecutive trials. The assessors were blinded to training status. Gallbladder dissection was 29% faster in the trained group. The authors concluded that use of VR significantly improved OR performance of residents during laparoscopic cholecystectomy. The above evidence is also supported by Reznick et al (15) who showed that VR training significantly improves a resident's ability to perform a laparoscopic cholecystectomy with a reduced rate of errors, higher economy of movement scores and faster dissection than residents with no training.

There have also been studies in gynaecology training programs that show laboratory-based training improves technical skills in a clinical setting. A core curriculum of intensive video laparoscopic skills training improved not only technical but operative performance among residents. A prospective randomised trial by Coleman & Muller (49) recruited obstetrics and gynaecology residents (skills cohort, 11; control cohort, 7) to laboratory based training for laparoscopic salpingectomy for treatment of ectopic pregnancy, compared to routine surgical training in residency. The aim of the study was to determine the effect and validity of an intensive laboratory-based laparoscopic skills training curriculum on operative proficiency. Study components included a baseline questionnaire, video skills testing, intraoperative skills assessment and resident skills perception. The residents that were assigned to a laboratory based skills curriculum had significantly higher ratings when performing a laparoscopic salpingectomy on patients. This study demonstrated that a short-term intensive laboratory-based video laparoscopic skills curriculum could translate into better individual operative proficiency. Banks et al (50) randomly assigned residents to a laboratory based surgical curriculum to teach laparoscopic tubal ligation versus routine surgical training. At baseline there were no differences in skills between the two groups. After completion of the curriculum, facility members blinded to the knowledge of which training the resident had received, assessed all residents in the operating room as to their ability to perform laparoscopic tubal ligation. Residents assigned to the simulation training obtained higher scores compared with the control group.

There is also good evidence to support the positive transfer of surgical skills after training with VR simulation. A recent study by Larsen et al (37) proved that skills in laparoscopic surgery could be increased in clinically relevant manner using proficiency based virtual reality simulator training. These researchers performed a prospective, randomized, observer blinded, controlled trial. A group of junior gynaecology registrars were divided into a control group and an intervention group (trained to proficiency on a VR simulator). The intervention group was given seven hours of training outside the normal service setting and was found to perform their first laparoscopy on a patient up to intermediate level (20-30 cases). The control group performed at a novice level (0-5 cases) and took twice as long to complete the procedure. The results showed that the performance of novices was increased to the level of intermediate experienced laparoscopists and the operation time to complete the task was halved. They were able to show that VR training in laparoscopic salpingectomy, compared with standard clinical education, was associated with a clinically important improvement of operative skills during the actual procedure. The learning curve in the OT was also shorter. By using simulator training it might be possible to bypass the early learning curve, which is known to be associated with a higher number of complications. These results also show that criterion based procedural training on a VR simulator can help compensate for reduced working hours by bringing trainees to a higher level of performance before they start training. They concluded that simulator training should be considered before trainees carry out laparoscopic procedures. This is possibly the first well-designed trial to show benefit from simulation in surgical training, and therefore has huge implications for the future.

Recently there have been a few structured reviews published which appraise the current value of simulation, their incorporation into the surgical curriculum and aim to address the question regarding positive transfer of skills (19,35,41,42,49,51-53). A systemic review by Sturm et al (51) attempted to determine whether skills acquired by virtual-reality training are directly transferable to the operative setting. Eleven studies were included; ten RCTs and one non-randomised comparative study. In most cases, simulation-based training was in addition to normal training programs. In conclusion, there is an overall positive effect of simulation-based training on the actual OR performance, although for some parameters transference was not demonstrated. Other systemic reviews have shown that there is a positive transfer of skills from the 'simulated' to the 'actual' operating environment, but only for certain surgical procedures (cholecystectomy, colonoscopy and sigmoidoscopy). A recent systemic review concluded that VR training improves standard surgical training (36) with preliminary data supporting the concept that these skills translate into more effective operating room performance (17,50). The methodologies were flawed weakening the strength of the conclusion.

11. Practice distribution

Practice distribution refers to the schedule of practice that a trainee is given. 'Distributed practice' refers to a practice schedule in which periods of training are interspersed with rest periods; 'massed practice' refers to a continuous block of uninterrupted training (54,55). With regard to the effectiveness of laparoscopic simulator training, it is unclear whether it is preferable to undergo 'distributed' training or 'massed' training. Meta-analytic reviews indicated that distributed training resulted in better retention of motor skills than massed training, although this difference was dependent on the tasks trained (56). MacKay et al (55) examined the effect of practice distribution in the medical setting. Forty-one novice subjects were randomised into one of three groups to train on a VR simulator. Group A trained for 20 min continuously (n=14), group B trained for 20 min in 5 min blocks (n=14) and group C trained for 15 min in 5 min blocks (n=13). Post training, all groups had a rest followed by a retention test. The authors reported that distributed endoscopic training on MIST VR, with short breaks, was superior to continuous training within one single day ($p=0.023$), as determined by the retention test. A later study randomly assigned students with no endoscopic experience to distributed VR training on three consecutive days (n=10) or distributed training within 1 day (n=10). The training involved 12 repetitions of three different exercises in three differently distributed training schedules. All students performed a post-test on a VR simulator seven days after training; three technical parameters were measured. The group with training over several days performed faster ($p=0.013$), with the same number of errors and instrument path length used suggesting that 'rest' results in better consolidation of skills (54). It would appear that distributed training is more effective than massed training, and over several days rather than training on one day, potentially having implications for workshop based programmes.

12. Training methods

Harold et al (57) compared two methods of instruction in a randomised fashion for the teaching of laparoscopic intracorporeal knot tying. The intervention group in this study received instruction by lecture, video, and individual proctoring, which was compared with instruction by manual alone. The intervention group performed better than the control group in this study. Participants in the intervention group had the advantage of not only better understanding through the use of video, but also the advantage of practice and proctoring, which allowed their understanding to be translated into performance.

Other recent randomised trials further reinforce the point that conceptual understanding and technical performance are both important elements of laparoscopic proficiency. Stefanidis et al (39) reported that a combination of video tutorials and limited feedback were the most efficient way to reach proficiency in a laparoscopic suturing curriculum. Korndorffer et al (58) reported that participants who received video and practiced performed better than those who received instruction by video alone. Leung et al (59) tested the efficacy of video as an educational tool in laparoscopic training. This RCT compared text versus video alone for a laparoscopic procedure. The results showed that video is superior to text alone for achieving quicker and better understanding and greater competency at performing laparoscopic tasks.

Snyder et al (60) randomised 36 medical students into independent or proctored training groups (n=18); no significant differences in demographics. Simulator proficiency was reached after a median of eleven hours of training (range 6-21 hrs.). Trainees in the independent group achieved proficiency with significantly fewer hours of training (HR 2.62; 95% CI, 1.01-6.85; p=0.048). The authors concluded that for proficiency-based VR simulator training, an independent approach was just as effective and potentially less time consuming for trainees than a proctored approach.

13. Skill retention

It is widely accepted that laparoscopic skills improve after simulator training, however little is known regarding skill retention. Surgical competency depends on a combination of procedural knowledge and skill retention. A meta-analysis found that performance decay increased with longer retention intervals; a 92% skill loss at one year was documented (61). More recently, Maagaard et al (62) looked at two groups (novices and experts) who performed 10 sessions on the LapSim VR. Assessment of skill was based on time, economy of movement and error. The authors reported that, although novices showed retention of skills after 6 months, after 18 months, laparoscopic skills had returned to pre-training levels. Sinha et al (63) documented the retention of motor skills over time in 33 surgical residents who trained to established criteria (and passed an exam) on seven technical skills on a VR. Six months after training the residents underwent repeat testing. At retest, significantly more residents failed clip applying and cutting tasks (p<0.05). In failed tests, instrument and tissue handling skills deteriorated more than the speed with which a task was completed. Evidence of skill retention was present for some but not all tasks. Fine motor skills

deteriorated more than skills needed for easier tasks. Residents were less likely to fail with increasing experience. Stefanidis et al (39) noted that there was a paucity of literature on skill retention and comparison of the durability of skill between VR and VT simulators. Fourteen surgical residents of varying levels were enrolled to train on VR and VT simulators until proficiency levels were achieved. VR scores were generated automatically and VT scores were based on completion time. Skill retention was evaluated by performing one task on both the VR (manipulate diathermy) and VT (bean drop) simulators. Skill acquisition was similar for both systems (Improvement:VR 59% vs. VT 56%). Despite an early performance decrement (VR 45% vs. VT 17%) the acquired skill persisted over a seven-month follow-up period. There was no correlation of skill loss with resident level, duration of training or any of the other parameters. The authors concluded that proficiency-based training on simulators results in durable skills, more so for VT than VR.

14. Assessment of Skills

The variable anatomy and different degrees of difficulty in live patients makes consistent assessment of technical skills in surgical trainees difficult. Traditionally trainee surgeons have been assessed by an 'expert' colleague, a process which is subjective and potentially prone to bias. A 'gold standard' for OR performance does not exist. Although improvement in surgical skill is usually reported, the extent of the improvement is hard to quantify. Therefore it is difficult to establish the effectiveness of simulation. More recently, studies have demonstrated the value of VR simulators for providing an objective assessment tool (64-67). Smith et al (68) developed a skills assessment device (SAD) incorporating VR and VT technology to quantify both speed and accuracy during laparoscopic skill performance. Untrained subjects performed ten repetitions of a standardised laparoscopic task. Task time improved dramatically during the first three repetitions and then stabilised. However, accuracy continued to improve. The authors concluded that although the time to perform a laparoscopic task improved more quickly than the accuracy of task completion, time alone is poor indicator of technical skill as it fails to account for the more protracted learning curve for accuracy. In their opinion, time was not a sufficient measure of proficiency.

Faster completion of a task does not presuppose accurate performance of the task (61,69). Both safety and accuracy need to be considered when assessing technical skills. Although a fast surgeon is not necessarily a safe surgeon, the idea that experience is related to greater efficiency of motion has face validity. Twenty-four subjects, with varying level of experience, were divided into three groups (naïve, junior, expert) depending on the volume of surgical experience. The results indicated that the 'time-error' scores are a valid measure of performance and improved significantly from baseline to final iteration in all groups. On all tasks, the 'expert' group performed significantly better than the naïve group (64). Furthermore, shorter times are indicative of familiarity and confidence with the instruments (28). Hyltander et al (70) found that students who performed tasks accurately also needed the least time. A technically skilled surgeon is one who executes a task quickly, is economical in movements as well as being precise (33). Studies have shown that performance, measured by either a subjective rating or time on a task, improve with practice (29,71,72).

15. Factors predicting performance

In laparoscopic surgery it is important to develop the ability to use both hands equally well. Many basic laparoscopic skills demand dexterity in both hands for successful completion of the task. Powers et al (73) assessed whether hand dominance had any effect on performance in a laparoscopic skills curriculum. Twenty-seven surgical residents underwent a four-week laparoscopic skills curriculum with pre- and post testing on six tasks during weeks one and four. During week two and week three, residents attended proctored practice sessions. The authors concluded that participation improved overall performance. The left-handed surgeons demonstrated better initial performance, but post-test comparison showed no difference.

Grantcharov et al (74) assessed impact of gender, hand dominance and computer games experience on psychomotor skills demonstrated with a VR simulator. Male surgeons were faster; no significant difference between genders in the number of errors and unnecessary movements was noted. Right-handedness was associated with fewer unnecessary movements. Computer game users made fewer errors than non-users. In a study by Derossis et al (29), forty-two surgeons viewed an introductory video, and then were tested performing seven laparoscopic tasks. Performance was measured using a scoring system rewarding precision and speed. Each candidate repeated all seven tasks and was rescored. Significant predictors of overall performance were level of training ($p=0.002$), repetition ($p=0.0001$) and interaction between level of training and practice (0.001). Construct validity was demonstrated by measuring significant improvement in performance with increasing residency training, and with practice.

As well as dealing with the stress of live operating, surgical trainees have to deal with many other stressors including unfavourable working patterns, sleep deprivation, large volumes of work and time pressures, concerns about patient outcomes, surgical emergencies or complications, team challenges, miscommunication and so forth. Andreatta et al (75) demonstrated that simulation provides an opportunity for trainees to manage stress in practice. They observed 27 medical students completing tasks using a laparoscopic simulator under two conditions; direct observation (stressor) and unobserved (no stressor). A simple stimulus of an evaluator observing the completion of a task incurred a stress reaction in terms of elevated heart rate and increasing performance errors. This has implications for training and assessment in the simulated context in that stressors imposed on the learner in a simulated environment may help support the acquisition of stress management skills that are necessary in the applied clinical setting. Exactly how these stressors influence surgical performance is not well understood, but simulation could be used to teach the trainee how to manage stress by developing coping mechanisms early in their training.

A primary aim for trainees is to practice skills in a safe and non-threatening environment. Evidence is accumulating which demonstrates a positive learning curve and improved surgical skills after training on surgical simulators. The availability of surgical simulators means that they can be incorporated into the surgical training curricula, and enable learning curves to be consigned to skills laboratories, away from live patients. The implementation of laparoscopy into residency training is difficult to achieve because of time and financial

constraints. However, the benefits of simulator training seem to be greatest for the most inexperienced surgeons, in acclimatizing to the 2D environment, new instrumentation and the fulcrum effect (76). This would suggest that the ideal time to introduce the concept of surgical skills training to trainees is during their surgical attachments as a medical student. Bearing in mind that simulation is an adjunct to, not a replacement for, traditional methods of training. Supervision and feedback are essential (77).

16. In summary

Some studies support the role of VR in surgical skills training; others support VT and claim that a greater improvement in skills acquisition occurs. Other studies show no difference between the two methods. Overall it is unclear which method is superior. The bottom line is that research has demonstrated that practice in surgical simulators leads to improved performance. Furthermore, there is evidence to show that simulator training translates into improved operative performance, but in a limited number of procedures. Further good quality studies are needed to strengthen the evidence base in support of the various types of surgical simulation, and to establish to what extent simulation should be part of the surgical training program.

17. In conclusions

The increasing popularity of MAS makes it imperative that junior doctors have ample opportunity to master basic laparoscopic skills. At present, despite three decades of development, MAS training is still rather primitive. Worldwide, surgical simulators are playing an increasing role in the training of junior doctors. Evidence is increasing on the nature of the acquisition of surgical skill through the use of simulators rather than the traditional approach. The optimal timing and means of acquiring and retaining these skills to ensure optimal transfer of skill to the operating room is unknown.

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