Serious games in surgical education
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Discussion

General Discussion, Conclusion and Future Perspectives
‘SAFE’ SURGICAL TRAINING

Approximately two decades ago, surgical educators set out to develop simulation programs to train and test their trainees before they commenced to practice surgery on patients. This was inspired by two developments. First, reports were published indicating disturbingly high mortality rates in hospitals due to human errors\(^1,^2\). Simultaneously, experiences during the implementation of minimally invasive surgery (MIS) indicated long learning curves of surgeons regarding this type of surgery. Virtual reality (VR) simulators were therefore developed and implemented\(^3\). Research shows that residents trained through these simulator-based programs operate faster, more efficient and make less errors than residents trained the conventional way\(^3,^4\). Simulation training is even thought to increase the cost-efficiency of surgical training, despite the initial development and maintenance costs\(^3,^5\). Simulation has therefore been introduced in the official surgical residency training and is becoming an accepted part of the curriculum\(^6–^9\). The training program of the Dutch Surgical Society (Nederlandse Vereniging voor Heelkunde) expresses the intent to implement simulation training curriculum-wide\(^7\).

Apart from basic MIS procedures, a full skills lab training program before the surgical trainee commences to operate in the ‘real’ surgical theatre is currently unrealistic. This has multiple causes. First, there is a shortage of available manpower and financial resources to implement simulation-based training structurally in daily hospital practice. Secondly, simulators do not trigger trainees’ inherent motivation to the extent that they keep practising voluntarily after reaching obligated levels of proficiency\(^10,^11\). Finally, Zevin et al\(^5\) and Schijven & Bemelman\(^8\) point out challenges regarding the implementation of simulation training in competency-based surgical training. These curricula require training and assessments with regard to not only technical skills (such as dexterity), but also knowledge and non-technical skills (such as collaboration, communication, leadership and task management). Simulation programs that integrate all three components comprehensively (knowledge, technical and non-technical skills) have yet to be developed\(^12\).

Serious games in surgical training

The recent advances in videogame design have led to the development of highly versatile, immersive and engaging virtual environments that prove to be able to teach users skills, knowledge and attitudes useful in real life\(^13–^15\). The General Introduction discusses that these serious or applied games have the potential to meet the challenges described above. Chapter 1 elaborates on the literature regarding the validity of serious games in postgraduate medical and surgical training in a systematic review. Serious games have been developed to train critical care-related non-technical skills, procedural steps in surgery, triage and multiple other objectives. Commercially available entertainment games have been applied to improve surgical trainees’ dexterity in MIS. Although
multiple studies evaluated these serious games, no definitive conclusions can be drawn regarding their validity. Furthermore, none are specifically designed for the purposes pointed out in the previous section (e.g. knowledge or non-technical skills in surgery).

Therefore, it is currently unclear if serious games can add to surgical training. The primary question regarding any new training modality is whether a new instrument is a valid method to train and assess a pupil. Essentially, validity concerns whether an instrument measures what it intends to measure and corresponds accurately to the real world. Validation of a training instrument encompasses multiple essential steps, referred to as content-, face-, construct-, concurrent and predictive validity (Table 1, Chapter 1).

The technology-enhanced surgical curriculum

It is unclear in what fashion serious games can add to the surgical curriculum. Ultimately, educators aspire to create a curriculum based on valid assessments of the trainee’s competencies in the context of their everyday clinical activities. The curriculum must therefore establish whether or not a trainee can be rightfully entrusted to perform a potentially hazardous procedure on real patients. Computer-based assessments, applied in both VR-simulators and serious games, could be very useful in this context. Both entities must therefore not be seen as competitive, but rather as complementary assets. The question remains how to design a curriculum that integrates these VR simulators and serious games validly and effectively. Combining both modalities in a technology-enhanced surgical curriculum has the potential to create a safe, engaging, effective and (thus) cheaper form of surgical training.

From this perspective, precedents are required to explore the possibilities with regard to the integration of serious games in the curriculum. It seems obvious to focus serious game-design on high-priority surgical activities. Chapter 2 describes a Delphi consensus survey on priorities of the clinical activities in the surgical curriculum. The surgical educators that participated regard basic laparoscopic procedures such as the laparoscopic cholecystectomy as one of the most important clinical activities for their trainees.

PROPOSAL FOR A TECHNOLOGY-ENHANCED PROGRAM FOR MINIMALLY INVASIVE SURGERY

Entrusting a trainee with responsibilities in the operating room should be based on his or her proficiency, as opposed to mere clinical exposure or quantity of procedures performed. Proficiency regarding a surgical procedure results from more than one’s technical skills: the trainee must also possess sufficient knowledge, non-technical skills and a sound surgical judgment in order to perform a procedure safely and effectively.
Ideally, the resident should acquire a predefined, validated level of proficiency compared to expert performance, before obtaining responsibilities in the surgical theatre. Aggarwal et al.\textsuperscript{20} describe a model for such a technology-enhanced proficiency-based curriculum (Figure 1). A structured five-phased approach guides the trainee systematically through the early learning stages towards obtaining responsibility in the surgical theatre\textsuperscript{20}. These individual phases are each concluded by a structured assessment, before the trainee moves on to the next: (1) knowledge-based learning, (2) task analysis, (3) skills training outside the operating room, (4) transfer of skills to the surgical theatre and (5) granting privileges for operating room practice (Table 1).

**Knowledge-based learning.**

Procedure-specific knowledge encompasses patient selection, diagnostic strategies, procedural preparation, post-operative management and recognition and management of complications\textsuperscript{20}. Trainees classically work through this phase by self-study. Tang et al. demonstrate that more errors performed by trainees in simulated exercises result from knowledge deficiencies than from technical incompetence\textsuperscript{21}. Whereas currently little structured training and assessment regarding knowledge takes place in the official curriculum, this learning phase may very well be under-appreciated.

Chapter 7 shows that quiz-games are excellent methods to train and assess surgical residents regarding knowledge. Interaction, competition and targeted feedback create
Discussion

A positive, stimulating experience. The quiz game directed at learning knowledge regarding bile stone disease and treatment (Medialis™, Little Chicken Game co., Amsterdam, The Netherlands) is generally accepted by trainees and is able to discriminate between different levels of clinical expertise (Chapter 7). In order to achieve proficiency-based assessment in the game, the trainees’ performance should be compared to the performance benchmarks set by experts.

An alternative to quiz-type serious games are simulation games. Games that simulate procedural steps (without actually performing the procedure manually), can be applied to teach procedural knowledge regarding knee arthroplasty surgery and coronary bypass surgery. Multiple smartphone-based procedural simulations are also available for this purpose. However, little is known regarding the validity of these training instruments.

Task analysis.

For a systematic approach regarding skills training and assessment in a simulated environment (VR simulator or serious game), it is necessary to decompose the specific procedure into subtasks. Through interviews and video analysis, these procedural subtasks and decisions can be determined, which are then used to construct a procedural workflow. This method has been applied to create part-task and VR simulators. Task analysis can also be used to create game-based training programs.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
<th>Training</th>
<th>Assessment</th>
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<tbody>
<tr>
<td>(1) Knowledge-based learning</td>
<td>Acquire procedure-specific knowledge</td>
<td>- Books</td>
<td>- Paper-based / oral examination</td>
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<td>- Didactic sessions</td>
<td>- Serious games</td>
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<td>- Video analysis</td>
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<td>- Workshops</td>
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<td>- Serious Game</td>
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<tr>
<td>(2) Deconstruction of procedure into tasks</td>
<td>Conduct hierarchical task analysis of specific procedures to develop training and assessment methods</td>
<td>- Lap Box trainer</td>
<td>- Lap Box trainer</td>
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<td></td>
<td></td>
<td>- Bench Model</td>
<td>- Cadaver model</td>
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<td></td>
<td></td>
<td>- Cadaver model</td>
<td>- VR Simulator</td>
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<td>- VR simulator</td>
<td>- Serious games</td>
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<td></td>
<td></td>
<td>- Serious Game</td>
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<tr>
<td>(3) Skills training</td>
<td>Acquire technical skills</td>
<td>- HF simulation</td>
<td>- HF simulations</td>
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<td></td>
<td></td>
<td>- Serious Game</td>
<td>- Serious games</td>
</tr>
<tr>
<td>(4) Transfer of skills to real environment</td>
<td>Demonstrate pre-defined level of proficiency in the operating room</td>
<td>- Lap Box trainer</td>
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<tr>
<td></td>
<td></td>
<td>- Cadaver model</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- VR Simulator</td>
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<td></td>
<td></td>
<td>- Serious Game</td>
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<td></td>
<td></td>
<td>- Live animal model</td>
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<tr>
<td>(5) Granting responsibilities in operating room practice</td>
<td>Progress to unsupervised performance of procedure</td>
<td>- Supervised practice</td>
<td>- Graded responsibility and combined assessment technical / non-technical skills / surgical judgment</td>
</tr>
</tbody>
</table>

**Table 1.** Technology-enhanced proficiency-based curriculum for MIS, with training and assessment modalities indicated. Abbreviations: HF = High-fidelity; Lap = Laparoscopic; VR = Virtual reality
Measuring a trainee’s proficiency requires a procedure-specific assessment. The workflow resulting from a procedural task analysis serves as basis for such an instrument, in which insufficiently or incorrectly completed subtasks are then scored as errors. Andersen and Cuschieri elaborate extensively on the design and application of task analysis-based assessment scales.

Skills training
In this phase, the trainee is equipped with the necessary technical and non-technical skills in a simulated environment. The acquisition of basic technical and non-technical skills in virtual reality environments allows for a higher level of learning in the real surgical theatre (such as decision-making and surgical judgment).

Technical skills
Basic technical skills curricula have been successfully implemented in surgical curricula, following the guidelines stated by the Dutch Society for Endoscopic Surgery (Nederlandse Vereniging voor Endoscopische Chirurgie). Different VR simulator types have the ability to improve trainees’ technical skills in reality (predictive validity). The guidelines state that technical skills required for different procedures differ. They therefore recommend a system of structured training and accreditation for specific laparoscopic procedures.

Before surgical trainees commence to practice MIS, they frequently assist experienced surgeons by navigating the laparoscopic camera. This is in fact a complex task, requiring specific visuo-spatial skills. However, structured camera navigation training methods have not yet been implemented. Chapter 9 shows the development and evaluation of a specific camera navigation curriculum for MIS. Surgical trainees and educators find the exercises to be realistic and useful. The instrument’s measurement system shows a discriminative ability between trainees with experience as primary surgeon and trainees without this experience. The distinct difference between experienced user groups and non-experienced user groups indicates the need for specific camera navigation training in MIS. Whereas this VR simulator’s basic skills curriculum is able to predict skills improvement in the operating room, there is sufficient evidence to implement this laparoscopic camera navigation curriculum in official surgical training.

The surgical trainee that commences to perform advanced MIS procedures, such as laparoscopic colectomies, requires a more advanced set of technical skills. Chapter 9 describes a Delphi consensus survey determining a consensus-based curriculum for this purpose, performed within a group of 17 European and North American laparoscopic colorectal surgery experts. The survey delivered a curriculum of eight distinct exercises on a previously validated laparoscopic VR simulator. The performances of nine advanced laparoscopic experts set benchmarks for trainees on this curriculum.
This study serves as an example for composing consensus-based skills curricula for specific surgical procedures. This method can be applied to compose both simulator- and game-based curricula, with regard to technical as well as non-technical skills training.

Virtual reality simulators alone do not motivate trainees to practice voluntarily\textsuperscript{10,11}. Literature shows that VR simulators can be \textit{gamified} to increase residents' adherence. This can be done by applying various game-derived mechanisms, such as competitions and rewards\textsuperscript{\textsuperscript{34}}. Next, specific commercially available entertainment games have shown to possess the ability to measure laparoscopic technical skills, suggesting their potential to become training modalities (Chapter 1). Moreover, custom-made videogames using laparoscopic handle controllers are able to distinguish laparoscopic expertise to an equal extent as VR simulators (\textit{concurrent validity})\textsuperscript{35}. As a result, it can be expected that simulator- and game producers will apply successful mechanisms from each other's designs, creating the most optimal user experience. The distinction between both modalities will subsequently fade away.

\textbf{Non-technical skills}

The increased dependence on technical equipment in MIS to visualise the operating field makes the surgeon more vulnerable for malfunctions that originate from outside his or her direct line of sight. The surgeon and surgical team must be able to correctly perceive, comprehend and react upon environmental signals, all in the context of the 'game plan'. This \textit{situational awareness} requires a combination of vigilance, diagnostic reasoning and problem-solving ability. Currently, there is no known training program for developing situational awareness in the surgical theatre.

Chapter 3 elaborates on the literature concerning methods to develop situational awareness in surgery in a systematic review. Although the available studies are limited in both quantity and quality, the most successful approach is thought to be through non-routine events training. The trainees practice managing adverse events in high-fidelity simulators, such as mock surgical theatres. This type of simulator's high costs and limited availability are however problematic for its practical application.

Surgical educators and game designers have therefore developed a serious game aimed at non-routine events training in an abstracted (and thus cheaper), challenging and entertaining setting. This approach is relatively novel to surgery. Chapter 4 shows that both surgical educators and surgical trainees from multiple centres in the Netherlands generally hold a positive attitude towards the concept of serious gaming and the game mechanism used. The majority of the participants acknowledged that the educational content was embedded realistically in the abstracted game setting.

Chapter 5 shows that the outcome parameters used in the serious game are able to discriminate between experts and non-experts. Groups that were considered experts (industry-related equipment experts) outperformed the inexperienced trainees. Howev-
er, surgeons and surgical trainees with considerable experience in MIS (>100 procedures as primary surgeon) did not outperform the novices, suggesting that current education in MIS is insufficient to equip professionals with the required practical skills to deal with equipment-related failure.

Chapter 6 shows that inexperienced surgical trainees trained through a game-enhanced curriculum, have a significantly greater ability to deal with non-routine environmental error than classically trained surgical trainees. In addition, there is a considerable (although non-significant) difference in number of problems recognized. This indicates that custom-made serious games have the ability to influence performance in the surgical theatre, and have the ability to influence non-technical skills.

The Dutch National Institute for Public Health (Rijksinstituut voor Volksgezondheid en Milieu, RIVM) has recently issued a report, stating that healthcare institutes should provide medical equipment training. Healthcare professionals should be assessed and granted permission to work with complex technology, such as laparoscopic equipment. This serious game proposes a convenient, valid and fun solution to provide such training. Hypothetically, this approach should improve the adherence to training and lead to ‘voluntary play’. This hypothesis should be the focus of research after the game is implemented in the standard surgical curriculum.

The most important step in the process of implementing non-routine events training in surgery will be to develop a consensus-based curriculum. Although surgical experts validated the serious game’s content, it only includes one type of laparoscopic tower and a limited amount of adverse event scenarios. Following the advances in technical skills training, experts from multiple centres should be consulted to construct the minimum requirements for a surgeon performing MIS independently. Lack of a structured curriculum could explain the varying results of the studies researching the effectiveness of non-routine events training (Chapter 3).

Skills transfer to the operation room

After skills’ training in virtual reality has brought the trainee’s performance to a predefined level of proficiency, he or she must demonstrate this proficiency in a controlled, real-to-life surgical simulation environment. Performance regarding basic technical skills in MIS can be assessed using the objective structured assessment of technical skills scale (OSATS).

Ideally, this phase should also include an assessment of trainees’ non-technical performance. Response to non-routine events, such as equipment failure scenarios, can be successfully measured in a live animal model setting (Chapter 6). If educators regard other non-technical skills equally relevant (e.g. team work and communication skills), it would be preferable to apply the validated Oxford non-technical skills rating scale
(NOTECHS), which has been validated in the surgical setting. The trainee should be allowed to pass if pre-defined proficiency levels on all domains are achieved.

**Granting privileges in the operating room**

In this proposed technology-enhanced curriculum, the resident starts to practice in the ‘real’ surgical theatre after successfully demonstrating skills proficiency on various models, in various scenarios, on all proposed levels (knowledge, skills, management). In the next phase, the trainee will receive more and more responsibility in performing the surgical procedure. Entrusting trainees to perform surgery with a limited amount of supervision results from a system of graded responsibility, which has already been implemented throughout surgical training in The Netherlands (Table 2). Educators currently judge this level of responsibility in a subjective fashion. The absence of an objective assessment system makes this judgement prone to time and personnel constraints. Future research should explore the value and validity of a combined objective assessment of trainees, using a combination of technical skills assessment (e.g. OSATS), non-technical skills assessment (e.g. NOTECHS) and surgical judgment (judgment analysis).

<table>
<thead>
<tr>
<th>Statement of awarded responsibility</th>
<th>Level of Supervision</th>
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<tbody>
<tr>
<td>1</td>
<td>Observing the activity</td>
</tr>
<tr>
<td>2</td>
<td>Acting with direct supervision</td>
</tr>
<tr>
<td>3</td>
<td>Acting with limited supervision</td>
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<tr>
<td>4</td>
<td>Acting unsupervised</td>
</tr>
<tr>
<td>5</td>
<td>Providing supervision to juniors</td>
</tr>
</tbody>
</table>

*Table 2.* Levels of responsibility awarded to the surgical trainee, while learning to perform a specific procedure.
CONCLUSION

Well-designed serious games grant new opportunities to educate surgical trainees in a wide variety of domains. Specific serious games can be regarded as valid instruments to train skills that are an inherent part of the surgeon’s expertise in a safe and engaging environment. Moreover, serious gaming can be used as relatively cheap method to improve important, yet frequently underestimated domains such as situational awareness and procedural knowledge. Before this potential can be truly effectuated, serious games have to be integrated into a structured curriculum, together with other modalities. Surgical educators stand for the challenge to develop procedure-specific consensus-based curricula in virtual reality environments.

FUTURE PERSPECTIVES

In surgical training, structured holistic training curricula for specific procedures are required. A smart combination of validated serious games and VR simulators is likely to create a tailored and flexible training experience for the surgical trainee. This will result in increasingly objective training and assessments of surgical trainees, before they operate on live patients. Virtual reality training in structured procedure-specific curricula grants the surgical trainee more control over his or her own education, reducing the dependence on busy supervisors and lack of exposure of specific surgical procedures.

When serious games become accepted methods for training and assessing skills, they could be applied for credentialing licensed medical specialists. This should imply the upkeep of relevant knowledge and dealing with non-routine events in the operating room. Moreover, game-based environments can be applied for credentialing medical specialists in working with complex medical and surgical equipment, as recent reports have suggested.36

The technological advances continue to stride forward. For example, the use of optical head-mounted displays can significantly enhance the level of immersion and fidelity of serious games and simulators in the near future. These applications can also place a virtual reality ‘layer’ over the real world (augmented reality). Augmented reality could not only be used to optimize training experiences, but also to assist the surgeon while performing ‘real’ surgical procedures, reducing the need for supervising surgeons present in the OR during the trainee’s more advanced stages of learning.
Discussion

KEY POINTS

- Serious games should only be applied when proven valid according to customary criteria.
- Custom-made serious games, co-created by developers and the medical community, are powerful instruments that can influence surgical trainees’ performance in the operating room.
- Surgeons and surgical trainees are likely to accept serious games as teaching modality.
- Knowledge-based learning should become standardized in the surgical training curriculum. Serious games could play an important part in this initial learning phase.
- Dealing with non-routine events is an important part of MIS training, whereas this requires non-technical skills that are not innate to the surgeon.
- A consensus-based non-technical skills curriculum should be established in MIS training.
- Surgical residents, medical students and OR nurses should not be allowed to practice laparoscopic camera navigation, before finishing a simulator-based technical skills curriculum.
- Every surgeon commencing to practice advanced laparoscopic surgical procedures should finish a procedure-specific validated curriculum.
- The MIS curriculum should include (1) procedure-specific requirements, (2) proficiency-based assessments and (3) validated simulators and serious games.
- All surgeons should acquire a wearable computer with an optical head-mounted display.
REFERENCES


