International Journal of Surgery xxx (2014) 1–8

Contents lists available at ScienceDirect

International Journal of Surgery

journal homepage: www.journal-surgery.net

Review

Simulation training: A review of simulation in arthroscopy and proposal of a new competency-based training framework

Charison Tay [a,*], Ankur Khajuria [a], Chinmay Gupte [a,b]

[a] Department of Surgery and Cancer, Imperial College London, Charing Cross Hospital, MSk Lab, 7th Floor, Lab Block, London W6 8RF, UK
[b] North West London Deanery Higher Surgical Rotation in Orthopaedics, UK

A R T I C L E I N F O

Article history:
Received 4 December 2013
Received in revised form
28 March 2014
Accepted 20 April 2014
Available online xxx

Keywords:
Simulation
Arthroscopy
Virtual reality
Training
Validity

A B S T R A C T

Introduction: Traditional orthopaedic training has followed an apprenticeship model whereby trainees enhance their skills by operating under guidance. However the introduction of limitations on training hours and shorter training programmes mean that alternative training strategies are required.
Aims: To perform a literature review on simulation training in arthroscopy and devise a framework that structures different simulation techniques that could be used in arthroscopic training.
Methods: A systematic search of Medline, Embase, Google Scholar and the Cochrane Databases were performed. Search terms included "virtual reality OR simulator OR simulation" and "arthroscopy OR arthroscopic".
Results: 14 studies evaluating simulators in knee, shoulder and hip arthroplasty were included. The majority of the studies demonstrated construct and transference validity but only one showed concurrent validity. More studies are required to assess its potential as a training and assessment tool, skills transference between simulators and to determine the extent of skills decay from prolonged delays in training. We also devised a "ladder of arthroscopic simulation" that provides a competency-based framework to implement different simulation strategies.
Conclusion: The incorporation of simulation into an orthopaedic curriculum will depend on a coordinated approach between many bodies. But the successful integration of simulators in other areas of surgery supports a possible role for simulation in advancing orthopaedic education.

1. Introduction

The conventional surgical training model – see one, do one, teach one – lacks the necessary elements to ensure consistent guidance, objective assessment of performance and feedback, and is difficult to justify in terms of patient safety, care and costs [1–4]. Shorter working hours in Europe [5] and America [6], has also been detrimental to surgical training and raised concerns over patient care and safety, and the acquisition of surgical skills for junior surgeons [7–10].

One possible method to address these issues is through simulation, which has long been used by the aviation industry to allow pilots control over their training environment while receiving structured, quantitative feedback without risk to passengers [11]. Parallels can be drawn between aviation and surgery as both involve work of a critical, stressful nature with time constraints [12].

Satava had originally proposed the use of virtual reality (VR) simulation as an adjunct to surgical training over a decade ago, recognising the enormous benefits and savings in time, cost, equipment and safety [13]. However its acceptance into surgical education was delayed then due to primitive technology, high expense, the lack of sensory input, inadequate scientific evidence supporting its role in surgical training and a lack of understanding of how to apply these simulations into a surgical training program. Many of these issues have now been remedied with the advent of newer technology providing more realistic simulations, haptic feedback and lower costs. Yet the improvement in technology does not validate the use of simulations in surgical training and requires individual surgical specialities to properly evaluate its use. Literature in general surgery has already shown a correlation between training on VR simulators and improved performance in the operating theatre [14–17]. However fewer studies have evaluated if this correlation applies in orthopaedic surgery. At the minimum, the simulator needs to demonstrate face validity, which is the extent to

* Corresponding author.
E-mail address: charison.tay09@imperial.ac.uk (C. Tay).

http://dx.doi.org/10.1016/j.ijsu.2014.04.005
1743-9191/© 2014 Published by Elsevier Ltd on behalf of Surgical Associates Ltd.

which the simulator is identical to real life scenarios. The ultimate aim of simulation studies would be to demonstrate concurrent validity, which would show that training on simulators is comparable with practice in the operating theatre as the gold standard (Table 1).

Arthroscopic education provides a unique area for the evaluation of simulation as a teaching tool because its use of video equipment, limited field of vision and grasping instruments including forceps, graspers and scissors, can be easily mimicked in an artificial setting. Hence simulation provides an opportunity to introduce a new method of teaching and evaluating arthroscopic skills.

2. Aims

To perform a review of the current literature on simulation training in arthroscopy and devise a framework that structures the different simulation techniques that could be used in arthroscopic training.

3. Methods

A search of Medline (PubMed), Embase, Google Scholar and The Cochrane Database was conducted using the search terms “simulator OR simulation” combined with “arthroscopy OR arthroscopic”. Inclusion criteria were English-language studies with evidence levels I, II, III and IV [18]. Exclusion criteria include non-English-language articles, scientific meetings/proceedings, pharmacological studies and biomechanical studies.

4. Results

4.1. Simulators as a training tool

A total of 14 studies met the inclusion criteria. Five studies [19–23] assessed simulated knee arthroscopy, eight studies [2,24–30] assessed simulator shoulder arthroscopy and one study [31] assessed simulated hip arthroscopy (Table 2). Seven studies [2,20,22,24–26,28] evaluated and demonstrated construct validity, nine studies [20,21,23,26–31] demonstrated transfer validity and one study showed concurrent validity [21].

Howells et al. [21] is the only arthroscopic simulator study to demonstrate concurrent validity to date. In this study, 20 junior orthopaedic trainees received traditional instruction and demonstrations of a diagnostic knee arthroscopy and were subsequently randomised to either a fixed arthroscopic simulator training protocol or received no additional training before performing the procedure in theatre under supervision by the same experienced orthopaedic surgeon who was blinded to the participant's training. Howells found that the simulator-trained group significantly outscored the control group on both the Orthopaedic Competence Assessment Project (OCAP) criteria and the Objective Structured Assessment of Technical Skill (OSATS) global rating scale [21] as assessed by the supervising orthopaedic surgeon, demonstrating that learning achieved on a simulator leads to better performance in the operating theatre.

Martin et al. [28] further showed that performance of trainees and surgeons on a standardised object localisation task on a VR shoulder arthroscopy simulator correlated with their performance of the same task on a cadaveric model. This is important, as cadaveric simulations have long been held as the next best mode of practice and teaching, below actual experience in the operating theatre. However due to the costs of maintaining a bioskills laboratory, specimen availability and concerns of uniformity of cadaveric specimens [32], simulators could supplant cadaveric simulations.

Table 1
Definitions of validity and reliability.

Type	Definition
Face Validity	Extent to which the simulator resembles clinical scenarios
Content Validity	Whether the domain or criteria being measured is actually being measured by the assessment tool or simulator
Construct Validity	Ability of the simulator to discriminate between different levels of expertise
Concurrent Validity	To what extent the results of the simulator correlates with the gold standard for the same domain
Transfer Validity	A measure of whether the system has the effect that it proposes to have (i.e. is the simulator able to produce a learning effect and improve performance with continued use)
Test-Retest Reliability	Similarity of results from a test when conducted at two different time points
Inter-Rater Reliability	Similarity of results from two or more different observers rating the performance of the same individual

4.2. Simulators as an assessment tool

Simulators may also be used in the assessment of basic orthopaedic skills. Vankipuram et al. [33] first described and evaluated the use of simulation for drilling, a basic orthopaedic skill that requires high levels of dexterity and expertise as inefficient drilling can be a source of complications with adverse effects. The study demonstrated that practice with the simulator tasks lead to an increase in proficiency on real tasks, with participants who practiced on the simulator prior to the practical test, performing better than participants who were put directly to the test [33]. Tashiro et al. [22] also proposed that simulations could be used to evaluate arthroscopic skills based on trajectory and force data after finding that experienced arthroscopic surgeons performed significantly better and faster on the Sawbones Knee Simulator than surgical trainees. Several studies have also validated [34] the use of, and have used motion analysis systems [23,27,31] as an objective assessment tool of arthroscopic skills; the commonest system used being a validated motion tracking system (PATRIOT; Polhemus, Colchester, Vermont).

4.3. Transference of skills between different simulators

The skills learnt from one simulator may not necessarily be transferred into similar or improved performance on a different simulator. It is assumed that more common components between two simulators would constitute greater similarity and greater transfer of skills whereas fewer common components would lead to a lesser degree of transfer. This was investigated by Strom et al. [19] who examined the performance of 28 medical students who initially trained on a Procedicus Virtual Arthroscopy (VA) Knee Simulator. 14 medical students then trained on three other simulators with different visual-spatial components; the Procedicus VA Shoulder, Procedicus MIST and Procedicus KSA Simulator, for an hour before all the participants were assessed again on the same task on the Procedicus VA Knee Simulator. The results showed no improvement in performance on the Procedicus VA Knee Simulator after training on the different simulators when compared with the control group who were only given training on a Procedicus VA Knee Simulator [19]. However the authors noted that the 1-h allocated to training on the different simulators may not have

Please cite this article in press as: C. Tay, et al., Simulation training: A review of simulation in arthroscopy and proposal of a new competency-based training framework, International Journal of Surgery (2014), http://dx.doi.org/10.1016/j.ijsu.2014.04.005

Table 2
Studies on simulation in arthroscopy.

Simulation	Author (Year)	No. of participants	Simulator type	Validity type	Method	Measured outcomes	Conclusion
Knee	Strom et al., (2004) [19]	28 medical students	Procedicus VA Knee Simulator	Quasi-Transfer (did not demonstrate)	Control Group ($n = 14$) performed a task to probe 6 locations throughout a virtual knee. Experimental Group ($n = 14$) Experimental Group received 1hr of training on 3 different simulators before performing the task.	Time to completion Movement economy Number of collisions with the scope Number of collisions with the probe	No significant difference was observed between the experimental and control groups in any of the analysed variables.
	McCarthy et al. (2006) [20]	23 orthopaedic surgeons	SKATS	Face Construct Transfer	Orthopaedic surgeons were split into 3 groups. Group 1 ($n = 6$) completed 5−50 knee arthroscopies Group 2 ($n = 7$) completed 51−100 knee arthroscopies Group 3 ($n = 12$) completed more than 1000 knee arthroscopies Participants tasked to find five loose bodies. 3 non-surgeon novices were also given 10 practice sessions to establish transfer validity	Time to completion Number of loose bodies (pathology) found Number of arthroscope tip to cartilage contact Scope path length Probe path length Probe observation score	Group 3 surgeons performed significantly faster, located more loose bodies and had shorter scope path length than Groups 1 and 2.
	Howells et al. (2008) [21]	20 orthopaedic trainees	Sawbones Knee Simulator	Transfer Concurrent	Orthopaedic trainees randomised to either 18 sessions of simulator training for a diagnostic knee arthroscopy or no additional training. All trainees received traditional instruction and demonstration.	Orthopaedic trainees were assessed on a diagnostic knee arthroscopy in the operating theatre by the same experienced orthopaedic surgeon, who was blinded to their status using OCAP and a modified OSATS.	Simulator-trained orthopaedic trainees had significantly higher scores on OCAP ($p = 0.0007$) and OSATS ($p = 0.0011$).
	Tashiro et al. (2009) [22]	30 surgeons	Sawbones Knee Simulator	Construct	Surgical trainees ($n = 12$) Orthopaedic trainees ($n = 12$) Orthopaedic surgeons ($n = 6$) Participants performed a knee joint inspection and probing task, and a partial meniscectomy.	Time to completion Path length of arthroscope scissors Path length of arthroscope probe Surgical force	The orthopaedic surgeons performed better than the orthopaedic trainees, who performed better than the surgical trainees.
	Jackson et al. (2012) [23]	19 orthopaedic trainees	Sawbones Knee Simulator	Transfer	All participants had an initial training phase where they performed 12 meniscal repairs on the simulator over 3-weeks. Group A ($n = 7$) trained once a month for 5 months Group B ($n = 6$) trained once, 3 months after the initial training phase Group C ($n = 6$) did not train All participants were assessed 6 months after the initial training phase 12 times over 3 weeks	Time to completion Total distance travelled by the surgeon's hands Number of hand movements	A learning curve was demonstrated in the initial training phase for all trainees. A plateau in performance was reached by 21st session for all residents. Group C did not show deterioration in performance after a 6 month interruption.
Shoulder	Pedowitz et al. (2002) [24]	78 participants with varying levels of experience	Procedicus Arthroscopy Simulator	Construct	Medical students ($n = 35$) Orthopaedic trainees ($n = 22$) Orthopaedic surgeons ($n = 21$) Participants performed a task	Time taken to touch each sphere Path ratio Number of probe collisions	Participants with greater arthroscopic experience performed better in path ratio

(*continued on next page*)

Table 2 (*continued*)

Simulation	Author (Year)	No. of participants	Simulator type	Validity type	Method	Measured outcomes	Conclusion
					using a probe to touch a sphere at 11 different locations in the joint	with tissue Injuries: collisions beyond the threshold force	and time taken to touch each sphere.
	Srivastava et al. (2004) [2]	35 participants with varying levels of experience	Procedicus Arthroscopy Simulator	Construct	Novice ($n = 21$) never performed a shoulder arthroscopy Intermediate ($n = 5$) performed 1-50 shoulder arthroscopies in last 5 years Expert ($n = 9$) performed >50 shoulder arthroscopies in last 5 years All participants completed the same study session with three modules.	Hook manipulation Anatomic identification Arthroscopic navigation	No difference was observed in anatomic identification. The expert group performed significantly better in hook manipulation and navigation.
	Gomoll et al. (2007) [25]	43 participants with varying levels of experience	Procedicus Arthroscopy Simulator	Construct	No surgical experience ($n = 8$) Junior orthopaedic trainees ($n = 11$) Senior orthopaedic trainees ($n = 14$) Orthopaedic surgeons ($n = 10$) All participants were tested on a standardised test protocol on the simulator	Time to completion Distance travelled with the probe Average velocity of probe movement Number of probe collisions	Participants' level of surgical experience correlated with their performance on the simulator in all parameters
	Gomoll et al. (2008) [26]	10 orthopaedic trainees	Procedicus Arthroscopy Simulator	Transfer Construct	10 orthopaedic trainees who were previously evaluated on the simulator were retested 3 years later after gaining further arthroscopic experience	Time to completion Distance travelled with the probe Number of probe collisions with tissue Average velocity of probe movement	All participants had significantly improved in all parameters
	Howells et al. (2009) [27]	6 orthopaedic surgeons	Alex shoulder professor	Transfer	6 lower-limb orthopaedic surgeons were instructed on the technique of an arthroscopic Bankart suture. They performed 3 single sutures each on 4 occasions and were re-tested 6 months later.	Total path length of hands Number of hand movements Time taken to perform the sutures	A learning curve with significant and objective improvement was demonstrated for all parameters. There was also a loss of all initial improvement in performance of the suture after 6 months.
	Martin et al. (2011) [28]	19 participants with varying levels of experience	InsightArthro VR Shoulder Simulator	Transfer Construct	Novice ($n = 15$) orthopaedic trainees Expert ($n = 4$) orthopaedic surgeons All participants were assessed on an object localisation task in the simulator three times. They were re-assessed at least 2 weeks later on a cadaveric simulator.	Time to completion	The performance of the participants on the simulator correlated with their performance on the cadavers. The expert group completed both the simulator and cadaveric tasks significantly faster than the novice group
	Martin et al. (2012) [29]	27 orthopaedic trainees	InsightArthro VR Shoulder Simulator	Transfer	Each orthopaedic trainee was assessed on the simulator annually for 3 consecutive years on an object localisation task. The trainee's surgical logbook was also analysed for total number of arthroscopies,	Time to completion Distance travelled with the probe Distance travelled with the camera	There was an inverse correlation between year of post-graduate training, the number of shoulder arthroscopies previously performed and time taken to completion of the task.

					shoulder arthroscopies and surgical cases.		
	Henn et al. (2013) [30]	17 medical students	Procedicus Arthroscopy Simulator	Transfer	Control Group ($n = 8$) Intervention Group ($n = 9$) All participants completed an initial baseline arthroscopy on a cadaveric shoulder. The intervention group subsequently received training on a simulator and all participants then repeated the same cadaveric arthroscopy	Time to completion Modified GOALS score	No difference at baseline. Intervention group was significantly faster than the control after training. Both intervention and control groups also had significantly better scores on repeat compared to their baseline.
Hip	Pollard et al. (2012) [31]	20 orthopaedic trainees	Hip Arthroscopy Bench-top Simulator	Transfer	Lateral Group Supine Group Each trainee performed 12 diagnostic hip arthroscopies across 4 weeks	Time to completion Total path length of hands Total number of hand movements	Initially, there was greater variability in the lateral group's learning curve but they caught up by episode 9. Both groups significantly improved from baseline.

been enough to substantially improve the performance of the participants in virtual arthroscopy tasks and experienced participants may be able to improve their performance by cross training on different simulators due to better knowledge and familiarity with different real-life scenarios and visual-spatial cues. Therefore the transfer of skills may require some specificity, with identical components required between two situations in order for the transfer to be successful. The transfer of a skill may also be possible between two situations if the skill has the same logical sequence in both situations although this would require investigation with further studies.

4.4. Prolonged delay in simulation training

Another interesting finding from the studies is the potential influence of a prolonged delay between training on the simulator on skills decay. Jackson et al. [23] found that a 6-month interruption between an initial training phase to perform a simulated meniscal repair on a knee arthroscopy simulator, and the final assessment phase, did not deteriorate the level of skill and performance of the participants who were all orthopaedic trainees. However the results of this study were disputed by Howells et al. [27] who found that in a group of fellowship-trained lower-limb surgeons taught to perform a Bankart suture on a shoulder arthroscopy simulator, there was a deterioration in their performance of the same procedure 6-months later without simulator training during the interval. This discrepancy in the retention of arthroscopic technical skills could be attributed to the participants in Howells' study being less receptive to retaining the skills that they learnt as they were lower-limb surgeons who had little vested interest in shoulder arthroscopy. On the other hand, participants in Jackson's study were orthopaedic trainees who had more of an incentive to retain the skills they learnt, as it may be applicable for them in the future. Hence it is possible that the learning and retention of arthroscopic technical, and possibly surgical, skills is both task- and surgical group-specific. Understanding the results of these studies may have practical implications such as whether different surgical specialities may share a basic set of surgical skills and if training on different surgical simulators may or may not help develop a particular skill for a certain surgical speciality.

For these simulators to become widely accepted and used as training and assessment adjuncts and tools, researchers will also need to introduce human factors and stressors into the simulation to more accurately represent the operating theatre environment. Additionally, most of the research has focused on arthroscopic models of simulation but only represents a fraction of procedures performed by orthopaedic surgeons. Hence further research is required to develop simulators that model other procedures.

4.5. Framework for arthroscopy simulation training

For the successful implementation of simulation into orthopaedic training, a competency-based curriculum is required that will allow simulation to be incorporated into the current form of surgical education. Such a curriculum however currently does not exist in the United Kingdom, however its potential is gaining traction and for the first time, the British Orthopaedic Association (BOA) has included a section on simulation as a training adjunct in its guidelines for trauma and orthopaedic curriculum, approved by the General Medical Council [35]. The guidelines provide 3 broad alternative simulation pathways through which orthopaedic trainees can use simulation as a training tool. We propose that for the purpose of arthroscopic learning, these pathways could be further narrowed down to a framework called the "Imperial College ladder of arthroscopy simulation" where trainees begin with being

Please cite this article in press as: C. Tay, et al., Simulation training: A review of simulation in arthroscopy and proposal of a new competency-based training framework, International Journal of Surgery (2014), http://dx.doi.org/10.1016/j.ijsu.2014.04.005

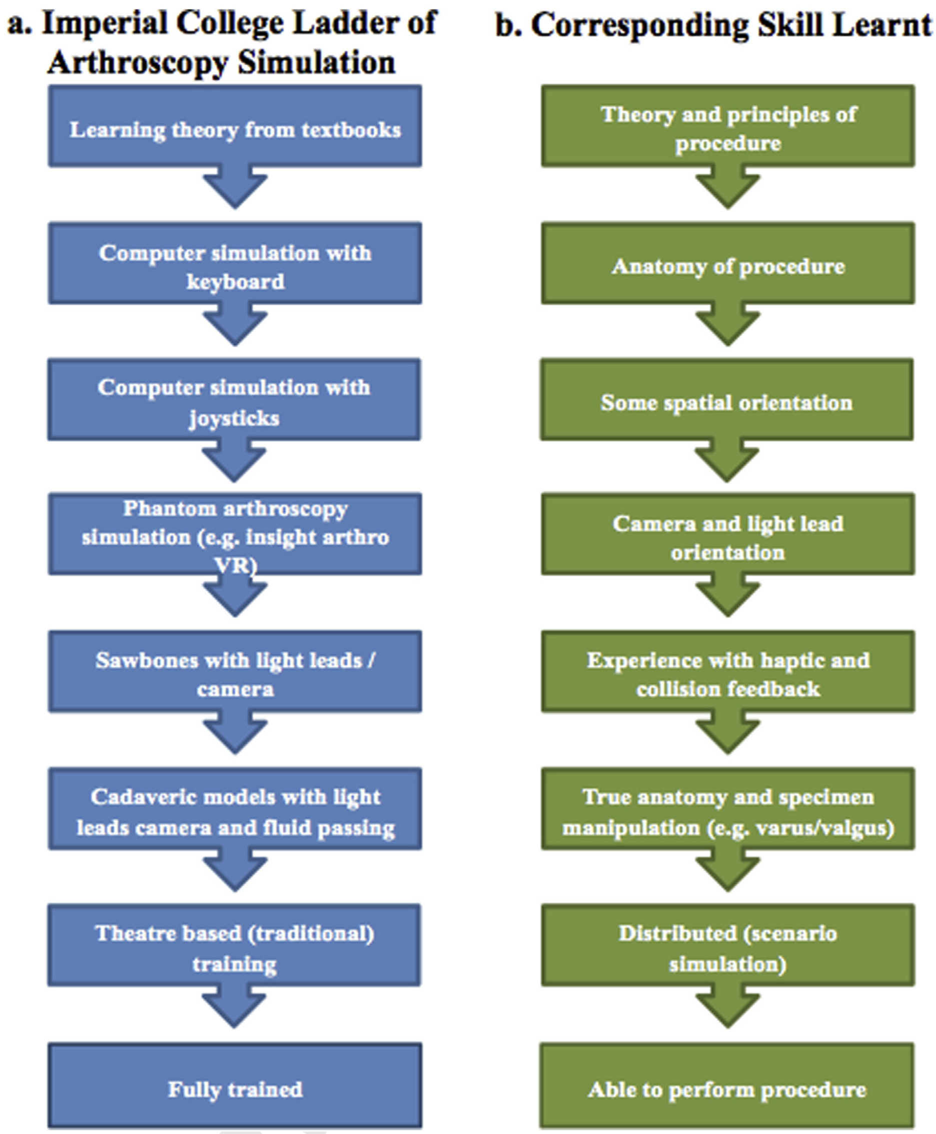

Fig. 1. a) Depicts the process through which trainees would train using the arthroscopy simulators and b) is the corresponding skills learnt at each step of the training ladder.

able to describe the theory and principles of the procedure, culminating with performing the procedure in the operating theatre (Fig. 1).

The ladder describes many different steps with a particular simulator-type ascribed to each. However practically, one simulator could be used for several steps, with the same simulator having different consoles such as joysticks, keyboards and grasping instruments attached to it. Many types of simulators have also been validated including SKATS, Sawbones Knee Simulator, Procedicus VA Knee Simulator, Procedicus Arthroscopy Simulator, Alex Shoulder Professor, InsightArtho VR Shoulder Simulator and Hip Arthroscopy Bench-Top Simulator. Its introduction will first require approval by accreditation bodies including the Specialist Advisory Committee and BOA with evaluation and assessment by randomised-controlled trials and feedback from participants.

We view this ladder merely as a framework for enabling the educator to select the right technique of simulation appropriate for the procedure, competency of the trainee and the facilities available. As such, it may be appropriate to join the ladder on a higher run without necessarily passing through the lower rung. Thus there is no compulsion to start at the lower rung of the ladder and work up to the next rung. Taking the example of an anterior cruciate ligament reconstruction, a junior trainee could perform the simulated surgery on an IPad application, "Touch surgery" [36] in order to learn the steps of the procedure. However a more senior trainee who has assisted in this operation several times may be familiar with the steps and hence can move straight to training on high fidelity simulations such as sawbones or cadaveric models.

5. Discussion

Arthroscopy has grown in popularity since its introduction in the 1960s as both a diagnostic and therapeutic tool [37]. It is however, a technically challenging and demanding technique to acquire and the current method of teaching and learning arthroscopic skills is associated with iatrogenic injury to the patient such as scuffing of the articular cartilage or missing pathologies [23,30]. The steep learning curve coupled with shorter working hours and less patient contact raises the concern of inadequate training and trainees have revealed that they feel less prepared and confident in arthroscopy compared with open procedures [38]. As such there is a move towards teaching and developing these skills outside the

Please cite this article in press as: C. Tay, et al., Simulation training: A review of simulation in arthroscopy and proposal of a new competency-based training framework, International Journal of Surgery (2014), http://dx.doi.org/10.1016/j.ijsu.2014.04.005

operating theatre and one way to do so is through the use of simulators.

It is easy to see that simulators can have many different applications in surgical education. Simulators may be used to instruct surgeons in the fundamentals of a procedure, assess their ability on objectively measured parameters, and allow skills required for an operation to be taught in a similar environment to that in which the skills will be used but without the pressures and distractions of an operating theatre. Predetermined criteria can also be used to assess a surgeon's progress in mastering a particular skill, thus allowing the learner to advance at their own individual speed. Surgeons can also use the simulators to rehearse and master complex and challenging operations, and overcome steep learning curves before coming into contact with a patient, thus ensuring patient safety and optimising the overall clinical experience of the surgeon at the same time. Simulators will also allow practicing surgeons to learn new laparoscopic and robotic techniques that may not be easily taught in an operating theatre.

Many studies have evaluated and demonstrated construct and transfer validity of a range of knee and shoulder simulators. However only one study has been published demonstrating concurrent validity in a sawbones knee simulator [21]. Hence more research is required to assess the feasibility of simulators as a tool to improve the technical skills of orthopaedic trainees before they enter the operating theatre.

5.1. Other methods of assessing training in arthroscopy

VR simulators can be used as an assessment tool using objective data collected by the simulators as the subject runs through in the simulation. However other forms of assessment tools could be used in conjunction with simulators to quantify performance. The most widely used method is an assessment form that consists of a scoring system grading the participant on several skills or categories with a numerical scale. Several such scales exist for the assessment of arthroscopic technique. For the knee, these include the Arthroscopic Skills Assessment Form [39], Modified Orthopaedic Competence Assessment Project [21], The Basic Arthroscopic Knee Scoring System [40], Objective Assessment of Arthroscopic Skills global assessment form [41] and The Arthroscopic Surgical Skill Evaluation Tool [42]. As for the shoulder, there is the Modified Global Operative Assessment of Laparoscopic Skills [30]. Additionally, the Objective Structured Assessment of Technical Skills [43] is a scoring system widely used across different surgical specialities and may also be applicable for the assessment of arthroscopic technical skills.

A scoring system for the non-technical aspects of surgery also exists, known as the Non-Technical Skills for Surgeons (NOTSS) rating system [44]. It consists of scores in 4 domains, situation awareness, decision-making, communication and teamwork, and leadership, all of which are applicable to the orthopaedic surgeon.

5.2. Challenges in implementation

Some of the challenges that directors of orthopaedic training programs may face include the cost of the simulators. The cost of an Alex II Shoulder Professor model (Pacific Research Laboratories Inc, Vashon, WA) is USD$682.75 whilst the cost of an arthroscopy knee model (Pacific Research Laboratories Inc, Vashon, WA) is USD$296.50 at the time of writing. These numbers do not take into account the software and hardware that some simulation laboratories may want to include in their simulators. Funding for simulators and facilities to house them may come from national grants or hospital funds, with the belief that any additional costs incurred from running a simulation facility will be recouped from potential savings in terms of shorter operating times and fewer complications due to better-trained orthopaedic trainees. Ultimately studies will be required to assess the cost-benefit analysis of running a simulation skills laboratory compared to the cost of teaching surgical trainees in the operating theatre.

Another challenge that teaching centres may face is having a dedicated space with faculty to take responsibility of the facility and training of the surgeons. A recent survey in the UK suggested that orthopaedic trainee access to a surgical skills simulator facility was 26.6%, well below the national average of 41.2% [45]. One possible solution is to have a shared facility between several hospitals in the same region and allocating training slots to each hospital. Additionally the trainer does not always have to be present when the trainee is using the simulator as the simulators can record and provide feedback on performance in real time and also allow the trainee to see how he or she is progressing over time. Hence trainees can schedule their training based on their schedule, adding some flexibility to the training program.

6. Conclusion

Many studies have validated construct and transfer validity on various simulators in arthroscopy. However only one study evaluated concurrent validity, which would be the next step in providing evidence that training on a simulator provides comparable development of skills compared to training in the operating theatre. Future development of simulators will also require detailed analysis of procedures and the identification of logical sequences of tasks to allow the transfer of skills from one procedure to another.

Ultimately the incorporation of simulation into an orthopaedic curriculum depends on a coordinated approach between many bodies. In the UK, these include the individual hospitals, national training bodies such as the joint committee on higher surgical training and local educational training boards, and medical education directors. The successful integration of simulators in other areas of surgery supports a possible role for simulation in advancing orthopaedic education.

Ethical approval

No ethical approval was required.

Funding

No funding was required.

Author contribution

Charison Tay: Conception and design of paper, review of the literature, drafting and final approval of the paper.

Ankur Khajuria: Conception, design, drafting and final approval of the paper.

Chinmay Gupte: Conception, design and final approval of the paper.

Conflict of Interest

The authors declare no conflict of interest.

Uncited references

[18]. Q3

References

[1] J.M. Rodriguez-Paz, M. Kennedy, E. Salas, et al., Beyond "see one, do one, teach one"-toward a different training paradigm, Postgraduate Medical Journal 85 (2009) 244–249.

[2] S. Srivastava, P.L. Youngblood, C. Rawn, S. Hariri, W.L. Heinrichs, A.L. Ladd, Initial evaluation of a shoulder arthroscopy simulator: establishing construct validity, Journal of Shoulder and Elbow Surgery/American Shoulder and Elbow Surgeons 13 (2004) 196–205.

[3] L.R. Farnworth, D.E. Lemay, T. Wooldridge, et al., A comparison of operative times in arthroscopic ACL reconstruction between orthopaedic faculty and residents: the financial impact of orthopaedic surgical training in the operating room, The Iowa Orthopaedic Journal 21 (2001) 31–35.

[4] M. Bridges, D.L. Diamond, The financial impact of teaching surgical residents in the operating room, American Journal of Surgery 177 (1999) 28–32.

[5] Department of Health. European Working Time Directive. [Online]. Available from: http://webarchive.nationalarchives.gov.uk/20130107105354/ (accessed 12.10.13).

[6] Accreditation Council for Graduate Medical Education. ACGME Duty Hours Archive: Approved Standards. Available from: http://www.acgme.org (accessed 12.10.13).

[7] C. Egan, R. Elliot, P. Fleming, European working time directive and the use of simulators and models in Irish orthopaedics, Irish Journal of Medical Science 181 (2012) 143–146.

[8] J.D. Zuckerman, E.N. Kubiak, I. Immerman, P. Dicesare, The early effects of code 405 work rules on attitudes of orthopaedic residents and attending surgeons, The Journal of Bone and Joint Surgery. American Volume 87 (2005) 903–908.

[9] K.J. Breen, A.M. Hogan, K. Mealy, The detrimental impact of the implementation of the European working time directive (EWTD) on surgical senior house officer (SHO) operative experience, Irish Journal of Medical Science 182 (2013) 383–387.

[10] R.J.E. Skipworth, J.D. Terrace, L.A. Fulton, D.N. Anderson, Basic surgical training in the era of the European working time directive: what are the problems and solutions? Scottish Medical Journal 53 (2008) 18–21.

[11] A. Mohan, M. Proctor, Virtual reality – a 'play station' of the future: a review of virtual reality and orthopaedics, Acta Orthopaedica Belgica 72 (2006) 659–663.

[12] J.D. Michelson, Simulation in orthopaedic education: an overview of theory and practice, The Journal of Bone and Joint Surgery. American Volume 88 (2006) 1405–1411.

[13] R.M. Satava, Virtual reality surgical simulator: the first steps, Clinical Orthopaedics and Related Research 442 (1993) 2–4.

[14] A.G. Gallagher, N.E. Seymour, J.A. Jordan-Black, B.P. Bunting, K. McGlade, R.M. Satava, Prospective randomized assessment of transfer of training (ToT) and transfer effectiveness ratio (TER) of virtual reality simulation training for laparoscopic skill acquisition, Annals of Surgery 257 (2013) 1025–1031.

[15] J.R. Korndorffer, J.B. Dunne, R. Sierra, D. Stefanidis, C.L. Touchard, D.J. Scott, Simulator training for laparoscopic suturing using performance goals translates to the operating room, Journal of the American College of Surgeons 201 (2005) 23–29.

[16] J. Price, V. Naik, M. Boodhwani, T. Brandys, P. Hendry, B.K. Lam, A randomized evaluation of simulation training on performance of vascular anastomosis on a high-fidelity in vivo model: the role of deliberate practice, The Journal of Thoracic and Cardiovascular Surgery 142 (2011) 496–503.

[17] D. Stefanidis, M.W. Scerbo, P.N. Montero, C.E. Acker, W.D. Smith, Simulator training to automaticity leads to improved skill transfer compared with traditional proficiency-based training: a randomized controlled trial, Annals of Surgery 255 (2012) 30–37.

[18] OCEBM Levels of Evidence Working Group. The Oxford 2011 Levels of Evidence. Oxford Centre for Evidence-Based Medicine. [Online]. http://www.cebm.net/index.aspx?o=5653 (accessed 10.10.13).

[19] P. Strom, A. Kjellin, L. Hedman, T. Wredmark, L. Fellander-Tsai, Training in tasks with different visual-spatial components does not improve virtual arthroscopy performance, Surgical Endoscopy 18 (2004) 115–120.

[20] A.D. McCarthy, L. Moody, A.R. Waterworth, D.R. Bickerstaff, Passive haptics in a knee arthroscopy simulator: is it valid for core skills training? Clinical Orthopaedics and Related Research 442 (2006) 13–20.

[21] N.R. Howells, H.S. Gill, A.J. Carr, A.J. Price, J.L. Rees, Transferring simulated arthroscopic skills to the operating theatre: a randomised blinded study, The Journal of Bone & Joint Surgery 90 (2008) 494–499.

[22] Y. Tashiro, H. Miura, Y. Nakanishi, K. Okazaki, Y. Iwamoto, Evaluation of skills in arthroscopic training based on trajectory and force data, Clinical Orthopaedics and Related Research 467 (2009) 546–552.

[23] W.F.M. Jackson, T. Khan, A. Alvand, et al., Learning and retaining simulated arthroscopic meniscal repair skills, The Journal of Bone and Joint Surgery. American Volume 94 (2012) e132.

[24] R.A. Pedowitz, J. Esch, S. Snyder, Evaluation of a virtual reality simulator for arthroscopy skills development, Arthroscopy: the Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association 18 (2002) E29.

[25] A.H. Gomoll, R.V. O'Toole, J. Czarnecki, J.J. Warner, Surgical experience correlates with performance on a virtual reality simulator for shoulder arthroscopy, The American Journal of Sports Medicine 35 (2007) 883–888.

[26] A.H. Gomoll, G. Pappas, B. Forsythe, J.J. Warner, Individual skill progression on a virtual reality simulator for shoulder arthroscopy: a 3-year follow-up study, The American Journal of Sports Medicine 36 (2008) 1139–1142.

[27] N.R. Howells, S. Auplish, G.C. Hand, H.S. Gill, A.J. Carr, J.L. Rees, Retention of arthroscopic shoulder skills learned with use of a simulator. Demonstration of a learning curve and loss of performance level after a time delay, The Journal of Bone and Joint Surgery. American Volume 91 (2009) 1207–1213.

[28] K.D. Martin, P.J. Belmonth, A.J. Schoenfeld, M. Todd, K.L. Cameron, B.D. Owens, Arthroscopic basic task performance in shoulder simulator model correlates with similar task performance in cadavers, The Journal of Bone and Joint Surgery. American Volume 93 (2011) e1271–e1275.

[29] K.D. Martin, K. Cameron, P.J. Belmont, A. Schoenfeld, B.D. Owens, Shoulder arthroscopy simulator performance correlates with resident and shoulder arthroscopy experience, The Journal of Bone and Joint Surgery. American Volume 94 (2012) e160.

[30] R.F. Henn III, N. Shah, J.J. Warner, A.H. Gomoll, Shoulder arthroscopy simulator training improves shoulder arthroscopy performance in a cadaveric model, Arthroscopy: the Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association 29 (2013) 982–985.

[31] T.C. Pollard, T. Khan, A.J. Price, H.S. Gill, S. Glyn-Jones, J.L. Rees, Simulated hip arthroscopy skills-learning curves with the lateral and supine patient positions, The Journal of Bone and Joint Surgery. American Volume 94 (2012) e68.

[32] W.D. Cannon, D.G. Eckhoff, W.E. Garrett Jr., R.E. Hunter, H.J. Sweeney, Report of a group developing a virtual reality simulator for arthroscopic surgery of the knee joint, Clinical Orthopaedics and Related Research 442 (2006) 21–29.

[33] M. Vankipuram, K. Kahol, A. McLaren, S. Panchanathan, A virtual reality simulator for orthopedic basic skills: a design and validation study, Journal of Biomedical Informatics 43 (2010) 661–668.

[34] N.R. Howells, M.D. Brinsden, R.S. Gill, A.J. Carr, J.L. Rees, Motion analysis: a validated method for showing skill levels in arthroscopy, Arthroscopy: the Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association 24 (2008) 335–342.

[35] General Medical Council. Approved Specialty Curriculum and Associated Assessment System 2013. [Online]. Available from: www.gmc-uk.org/ (accessed 24.10.13).

[36] Touch Surgery. [Online]. http://www.touch-surgery.com (accessed 12.03.14).

[37] W.E. Garrett Jr., M.F. Swiontkowski, J.N. Weinstein, et al., American board of orthopaedic surgery practice of the orthopaedic surgeon: part-II, certification examination case mix, The Journal of Bone and Joint Surgery. American Volume 88 (2006) 660–667.

[38] M.P. Hall, K.M. Kaplan, C.T. Gorczynski, J.D. Zuckerman, J.E. Rosen, Assessment of arthroscopic training in U.S. orthopaedic surgery residency programs: a resident self-assessment, Bulletin of the NYU Hospital for Joint Diseases 68 (2010) 5–10.

[39] M.J. Elliott, P.A. Caprise, A.E. Henning, C.A. Kurtz, J.K. Sekiya, Diagnostic knee arthroscopy: a pilot study to evaluate surgical skills, Arthroscopy: the Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association 28 (2012) 218–224.

[40] A. Insel, B. Carofino, R. Leger, R. Arciero, A.D. Mazzocca, The development of an objective model to assess arthroscopic performance, The Journal of Bone and Joint Surgery. American Volume 91 (2009) 2287–2295.

[41] J.A. Slade Shantz, J.R. Leiter, J.B. Collins, P.B. MacDonald, Validation of a global assessment of arthroscopic skills in a cadaveric knee model, Arthroscopy: the Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association 29 (2013) 106–112.

[42] R.J. Koehler, S. Amsdell, E.A. Arendt, et al., The arthroscopic surgical skill evaluation tool (ASSET), The American Journal of Sports Medicine 41 (2013) 1229–1237.

[43] C.P. Winckel, R.K. Reznick, R. Cohen, B. Taylor, Reliability and construct validity of a structured technical skills assessment form, American Journal of Surgery 167 (1994) 423–427.

[44] S. Yule, R. Flin, N. Maran, D. Rowley, G. Youngson, S. Paterson-Brown, Surgeons' non-technical skills in the operating room: reliability testing of the NOTSS behaviour rating system, World Journal of Surgery 32 (2008) 548–556.

[45] J.A. Milburn, G. Khera, S.T. Hornby, P.S. Malone, J.E. Fitzgerald, Introduction, availability and role of simulation in surgical education and training: review of current evidence and recommendations from the association of surgeons in training, International Journal of Surgery (London, England) 10 (2012) 393–398.

Please cite this article in press as: C. Tay, et al., Simulation training: A review of simulation in arthroscopy and proposal of a new competency-based training framework, International Journal of Surgery (2014), http://dx.doi.org/10.1016/j.ijsu.2014.04.005