Testing the Construct Validity of a Virtual Reality Hip Arthroscopy Simulator

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Purpose: To test the construct validity of the hip diagnostics module of a virtual reality hip arthroscopy simulator. **Methods:** Nineteen orthopaedic surgeons performed a simulated arthroscopic examination of a healthy hip joint using a 70° arthroscope in the supine position. Surgeons were categorized as either expert (those who had performed 250 hip arthroscopies or more) or novice (those who had performed fewer than this). Twenty-one specific targets were visualized within the central and peripheral compartments; 9 via the anterior portal, 9 via the anterolateral portal, and 3 via the posterolateral portal. This was immediately followed by a task testing basic probe examination of the joint in which a series of 8 targets were probed via the anterolateral portal. During the tasks, the surgeon's performance was evaluated by the simulator using a set of predefined metrics including task duration, number of soft tissue and bone collisions, and distance travelled by instruments. No repeat attempts at the tasks were permitted. Construct validity was then evaluated by comparing novice and expert group performance metrics over the 2 tasks using the Mann−Whitney test, with a P value of less than .05 considered significant. **Results:** On the visualization task, the expert group outperformed the novice group on time taken ($P = .0003$), number of collisions with soft tissue ($P = .001$), number of collisions with bone ($P = .002$), and distance travelled by the arthroscope ($P = .02$). On the probe examination, the 2 groups differed only in the time taken to complete the task ($P = .025$) with no significant difference in other metrics. **Conclusions:** Increased experience in hip arthroscopy was reflected by significantly better performance on the virtual reality simulator across 2 tasks, supporting its construct validity. **Clinical Relevance:** This study validates a virtual reality hip arthroscopy simulator and supports its potential for developing basic arthroscopic skills. **Level of Evidence:** Level III.

With an ever-increasing number of diagnostic and therapeutic indications, hip arthroscopy is one of the most rapidly expanding areas of modern surgery.[1-4] The ball-and-socket nature of the joint, together with the thickness of the capsule and soft-tissue envelope, make it a technically demanding field with a steep learning curve.[2] An estimated 30 training cases are required before a reduction in complications is observed.[5] Such complications include labral or chondral injury from instrumentation, bleeding or nerve injury from portal insertion, and traction-related neurapraxia.[6] It is therefore vital that orthopaedic surgeons gain exposure to arthroscopic hip surgery early in their training and quickly develop the basic skill set necessary to progress towards competency.

Although the traditional model of the apprenticeship in surgical training still applies today, the evolution of more technically demanding surgical techniques combined with a reduction in the trainee's caseload has led to steep learning curves in the modern era.[7-11] Several studies have highlighted the length of time taken to become a safe and effective arthroscopic surgeon, demonstrating both increased operative time and a greater incidence of complication when an inexperienced clinician is performing arthroscopic hip surgery.[12-14]

Multiple studies have also suggested a role for virtual reality (VR) simulation in overcoming this steep learning curve by equipping the orthopaedic trainee with the basic skill set required to safely perform arthroscopic procedures.[15-17] In the context of hip

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The authors report the following potential conflict of interest or source of funding: V.K. is an educational consultant for Smith and Nephew.

Received April 26, 2016; accepted September 26, 2016.

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0749-8063/16346/$36.00

http://dx.doi.org/10.1016/j.arthro.2016.09.028

Table 1. Summary of Participant Demographics

Group	Mean Age, y	Mean Height, cm	Sex, Male/Female	Total Years Surgical Practice	Mean Number of Hip Arthroscopies Performed
Experienced	46.7 ± 5.7	180.5 ± 7.7	9:0	20.1 ± 4.7	911.1 ± 492.9
Novice	38.5 ± 6.8	177.7 ± 6.2	10:0	8.7 ± 6.0	9.1 ± 26.9

arthroscopy, improving skills with simulation before performing a procedure in the operating room has the potential to reduce those complications associated more closely with surgical technique, such as labral and chondral injury. Validation of a VR hip arthroscopy simulator as an evaluation tool is required before it can be used to this end.

The purpose of this study was to test the construct validity of the hip diagnostics module of a VR hip arthroscopy simulator by comparing novice and expert performance over 2 tasks of increasing difficulty. The hypothesis was that expert arthroscopic hip surgeons would achieve superior performance on the simulator compared with those with little experience, supporting the simulator's construct validity.

Methods

For this study, orthopaedic surgeons were recruited voluntarily after 1 day of a cadaveric training course in arthroscopic hip surgery for orthopaedic residents in December 2015. The study was open to all surgeons participating in the course. This included the surgical residents (surgeons at various stages of a 6-year specialty training program in orthopaedic surgery) as well as course faculty members (practicing orthopaedic surgeons who have successfully completed the 6-year training programme and gained certification as orthopaedic specialists). The first day of the course covered the equipment used in arthroscopy of the hip joint (including the 70° arthroscope and probe set), portal placement in the supine and lateral positions, applied anatomy of the hip joint, and finally visualization of the central and peripheral compartments in cadaveric specimens. Basic demographic information was provided by each volunteer, including sex, age, height, and glove size, as well as detailed information on their surgical experience and any previous use of VR simulation (Table 1). A cut-off of 250 independent hip arthroscopies was used to classify participants as novice (less than 250 arthroscopies) or expert (250 arthroscopies or more). This number was taken from the competency criteria published by the German Speaking Society of Arthroscopy; the only formal published criteria for proficiency in arthroscopy.[18]

The Simbionix Arthro Mentor (Simbionix, Airport City, Israel) VR simulator was used for this study. This simulator consists of a mannequin with fixed 5-mm portals at the anterior, anterolateral, and posterolateral sites, a 70° arthroscope, a rounded 5-mm blunt tip probe, a computer, and a monitor that produces

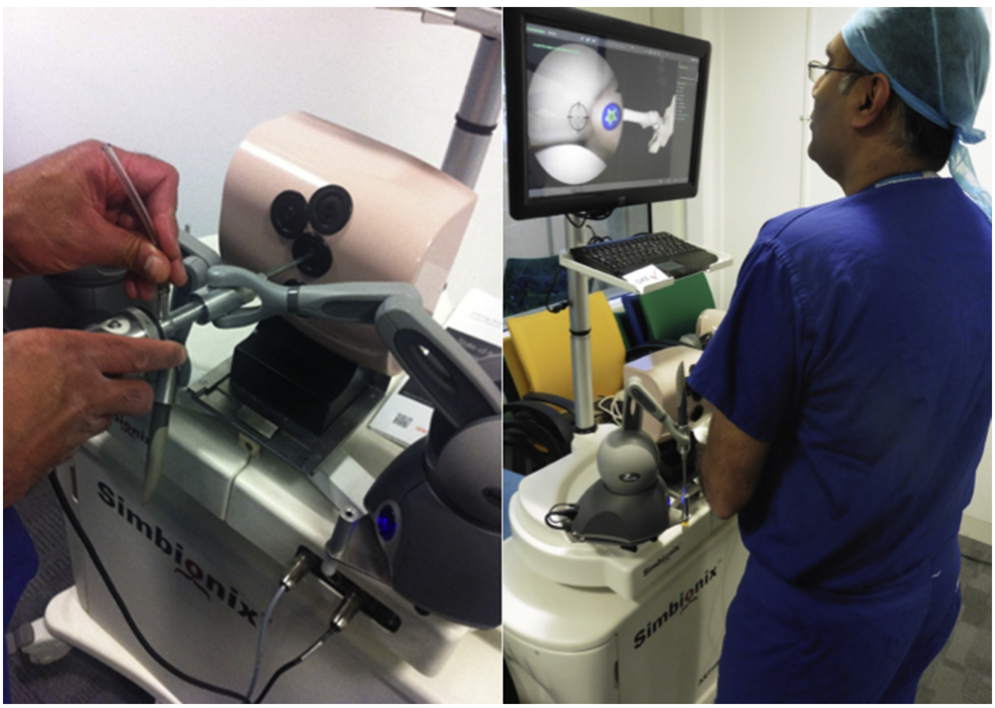

Fig 1. User interface on the Simbionix Arthro Mentor.

Table 2. List of Targets to Be Visualized From Each Portal in the Visualization Task

Portal Site	Targets to Be Visualized During Task
Anterior	Acetabular fossa
	Ligamentum teres
	Posterior transverse ligament
	Anterior transverse ligament
	Posterior labrum
	Anterior labrum
	Superior labrum
	Anterior acetabulum
	Posterior-superior capsule
Anterolateral	Acetabular fossa
	Posterior acetabulum
	Ligamentum teres
	Posterior labrum
	Anterior labrum
	Superior labrum
	Anterior triangle
	Posterior capsule
	Femoral head
Posterior	Weight-bearing acetabulum
	Posterior-superior labrum
	Femoral head

3-dimensional images in response to the actions of the operator. The simulator provides haptic feedback for the operator via motors connected to the instruments (Fig 1). Each participant was asked to perform 2 consecutive simulated procedures in the supine position; 1 basic visualization task and 1 basic probe examination of the joint (Video 1, available at www.arthroscopyjournal.org).

Each task began with identical written instructions on-screen, with the procedure time starting on insertion of the arthroscope into any of the 3 portals (anterior, anterolateral, and posterolateral). The visualization task involved locating a series of 21 targets using 3 arthroscopy portals. Nine targets were visualized via the anterolateral portal, 9 via the anterior, and 3 via the posterolateral (Table 2). Targets were located on specified areas of a healthy hip joint, and participants were required to place them in clear view on the center of the monitor for 3 seconds before the simulator selected the next target. The order in which targets appeared remained the same for each participant.

The basic probe examination involved visualizing a series of 8 targets via the anterolateral portal and achieving sustained contact with them for 3 seconds using a probe inserted through the portal of the participant's choice (Fig 2). As with the visualization task, the order of targets remained the same for each participant (see Table 3). During the tasks, the surgeon's performance was evaluated by the simulator via a set of predefined metrics procedure duration, time elapsed between targets, number of soft tissue and bone collisions, total length of any femoral head scratches performed by the instruments, camera-tissue contact time, and distance travelled by instruments.

Statistical analysis was performed with version 3.2 of R (Foundation for Statistical Computing, Vienna, Austria). Differences in the performance metrics between the expert and novice groups were compared with the Mann−Whitney test, with a P value of less than .05 considered significant. Normality of distribution was tested with the Shapiro-Wilk test. Correlation between participant variables (years of surgical experience and number of hip arthroscopies performed) and outcome measures was tested using Pearson product-moment correlation coefficient.

Results

Ten surgical residents (surgeons at various stages of a 6-year specialty training program in orthopaedic surgery) and 9 faculty members (practicing orthopaedic surgeons who have successfully completed the 6-year

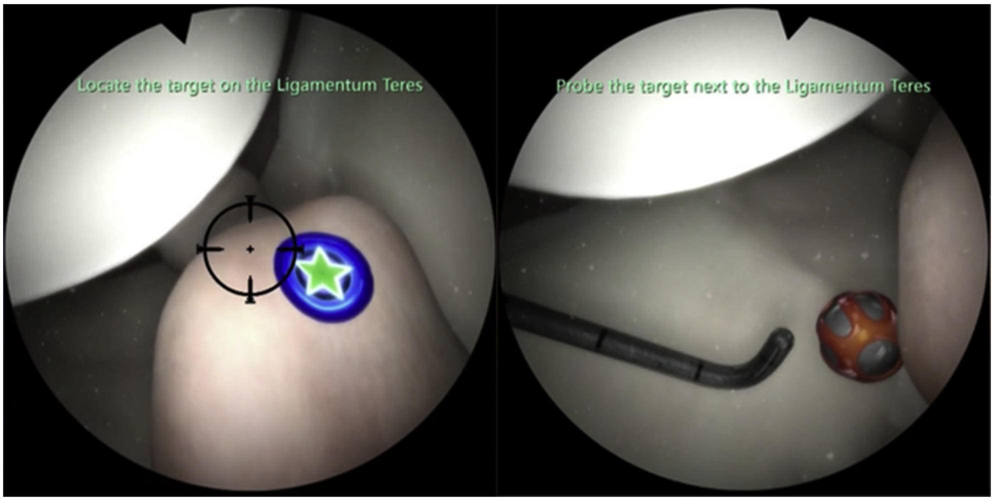

Fig 2. Screenshots of the visualization task (left) and the probe task (right).

Table 3. Targets to Be Probed During the Basic Probe Examination Task

Portal Site	Targets to Be Probed During Task
Anterolateral	Acetabular fossa
	Posterior acetabulum
	Ligamentum teres
	Anterior triangle
	Anterior paralabral sulcus
	Anterior labrum
	Posterior capsule
	Femoral head

training programme and gained certification as orthopaedic specialists) volunteered for the study. All 9 faculty members had performed 250 hip arthroscopies or more, forming the expert group, with all 10 surgical residents performing less than this number, forming the novice group. All but 1 of the expert group had performed more than 500 hip arthroscopies, in contrast to the novice group, in which only 1 surgeon had performed 10 or more hip arthroscopies. None of the participants had previous experience of using a hip arthroscopy simulator. There were no exclusions from analysis.

On the visualization task, the expert group significantly outperformed the novice group, as measured by the time taken to complete the task (P = .0003), number collisions with soft tissue (P = .001), number of collisions with bone (P = .002), total contact time between the arthroscope and tissues (P = .001), and distance travelled by the arthroscope (P = .023) (Table 4). There was no significant difference in total length of femoral head scratches (P = .10) or camera steadiness (P = .45). On the basic probe examination, the 2 groups differed only in time taken to complete the task (P = .025) and total contact time between the arthroscope and tissues (P = .014), with no difference noted in any other outcome measures (Table 5).

On the visualization task, there was moderate inverse correlation between years of surgical experience and the number of tissue collisions ($r^2 = -0.68$) and moderate correlation between the number of previous hip arthroscopies performed and time taken to complete the task ($r^2 = -0.62$). On the basic probe examination, there was no correlation between participant variables, including number of previous hip arthroscopies performed and number of hip arthroscopies performed per week, and outcome measures.

Discussion

These results demonstrate a statistically significant difference between the performance of experts and novices on a VR hip arthroscopy simulator, with experts performing superiorly across 2 consecutive tasks. This finding implies that skill in the operating room is reflected on the simulator, supporting the simulator's construct validity. These results mimic those of similar studies relating to the use of VR simulation in orthopaedic training and support the hip arthroscopy simulator's use in helping trainees gain the basic skill set necessary to train in hip arthroscopy.[19-24]

For simulation to have maximal benefit in the clinical setting, it should achieve not only a technical familiarity with hip arthroscopy but also a familiarity with basic procedures. In this regard, evidence supporting VR simulation in training orthopaedic surgeons is still minimal, with few studies of arthroscopy simulation showing the benefits to the trainee in the operating room. A study by Howells et al.[25] in 2008 showed trainees randomized to receive simulator training in addition to their standard surgical curriculum achieved significantly improved competence scores when performing a diagnostic knee arthroscopy in the operating room. A subsequent study by Cannon et al.[26] in 2014 had similar findings, with trainees randomized to receive simulator training showing superior probing skills when performing diagnostic knee arthroscopy in the operating room, although procedure duration and visualization skills did not differ between the 2 groups. A 2015 study by Angelo et al.[27] showed increased likelihood of proficiency in performing an arthroscopic Bankart repair at the completion of training when trainees were randomised to receive simulation training in addition to the standard curriculum.

Although these studies are encouraging, this relative lack of evidence contrasts with other surgical specialties such as general surgery, in which a much larger number of studies have demonstrated the positive effects of simulator training on operating room performance.[28-34] If the orthopaedic community is to commit to the use VR training, clinicians must continue to work closely with technology companies to both develop VR simulation and investigate the effects of simulator use on trainee performance across a broad range of clinical settings, including arthroscopic hip surgery.

One aspect of VR simulation that may limit its application is the cost of purchasing and maintaining a

Table 4. Results of the Basic Visualization Task

	Time Taken, min	Soft Tissue Collisions, n	Bone Collisions, n	Camera-Tissue Contact Time, min	Distance Traveled by Arthroscope, cm	Length of Femoral Head Scratches, mm
Experienced	14.0 ± 5.0	61.6 ± 14.1	51.7 ± 14.5	9.5 ± 4.9	593.4 ± 299.9	450.2 ± 165.6
Novice	24.7 ± 6.2	111 ± 38.3	78 ± 20.3	17.2 ± 4.4	922.7 ± 348.2	582.1 ± 190.9
P value	<.001	.001	.002	.001	.020	.062

Table 5. Results of the Basic Probe Examination Task

	Time Taken, min	Soft Tissue Collisions, n	Bone Collisions, n	Camera-Tissue Contact Time, min	Distance Travelled by Arthroscope, cm	Length of Femoral Head Scratches, mm
Experienced	10.6 ± 6.3	47.2 ± 37.9	35.3 ± 31.3	5.4 ± 2.9	272.1 ± 201.3	288.3 ± 238.5
Novice	19.4 ± 10.3	88.3 ± 68.3	63.8 ± 46.5	13.7 ± 9.0	420.9 ± 250.7	574.6 ± 655.1
P value	.025	.072	.078	.013	.181	.124

simulator. This cost may be prohibitive for some surgical units and prevent simulation from entering the curriculum on a national level. Health-economic evaluations of simulation as a training method, however, have shown them to be cost-effective when compared with traditional methods of training,[35-37] which suggests that VR simulators that have construct validity and a proven benefit to the trainee in the clinical environment represent a sensible investment for the training of surgeons.

Limitations

One limitation in this study is that it was performed during the course of a single day. A more precise analysis of the benefits in terms of skill acquisition could be achieved by repeating a single task multiple times with a fixed interval between attempts. This would provide more information on skill retention and learning curves over time, an important factor when considering the utility of VR simulator training.[38]

Unlike some previous studies of simulation, the number of previous procedures and years of experience showed only moderate correlation with simulator performance metrics.[39] This is in keeping with suggestions from previous studies that beyond the initial learning curve of arthroscopy, a "plateau" phase is reached in which performance is more susceptible to natural variation, preventing any obvious trends from being observed.[11] This study, however, is limited in that sample size was dictated by the number of surgeons attending the course and their willingness to participate, rather than by performing a priori power calculations. Furthermore, the novice group had almost no experience of arthroscopy. Studies involving larger numbers of participants with a wide range of experience would be useful in exploring these trends further.

When designing the study, we opted to use the competency criteria published by the German Speaking Society of Arthroscopy (250 independent arthroscopies) as a cut-off value that defined a surgeon as an expert; however, these criteria are currently used with reference to knee arthroscopy only and cannot be assumed to apply to arthroscopy of the hip joint. Unfortunately there are no formal criteria for defining an expert in hip arthroscopy.

Although we are able to objectively support the use of VR simulation to develop the basic skill set necessary for hip arthroscopy, it is more challenging to evaluate the role of the simulator in familiarizing the trainee with particular procedures. A limitation of this study in this respect is that the tasks performed did not fully replicate the basic arthroscopic examination. Although the targets for visualization and probing were located in clearly defined and appropriate anatomical areas, the fixed order in which they appeared was not in keeping with the sequence of an arthroscopic examination. Furthermore, the data analysis performed by the simulator is limited in that it does not isolate particular parts of the task a participant found challenging. For example, it would be valuable for a trainee to discover in a simulated setting that they were most likely to cause tissue damage while visualizing the posterior labrum.

Although the images and movements produced by the simulator were highly realistic, the haptic feedback was less so, which was reflected in the high number of tissue and bone collisions recorded during the tasks, which were far greater than one would expect during arthroscopy in the clinical setting. Although these observations mean this simulator is likely to lack face validity, we were unable to gain sufficient feedback from participants to draw conclusions to this end.

Conclusions

Increased experience in hip arthroscopy was reflected by significantly better performance on the VR simulator across 2 tasks, supporting its construct validity.

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