Virtual Reality Simulation Training can Improve Inexperienced Surgeons’ Endovascular Skills

R. Aggarwal,1* S.A. Black,1,2 J.R. Hance,1 A. Darzi1 and N.J.W. Cheshire1,2

1Department of Biosurgery and Surgical Technology, Imperial College London, and 2Regional Vascular Unit, St Mary’s Hospital, London, UK

Purpose. The aim of this study was to evaluate virtual reality (VR) simulation for endovascular training of surgeons inexperienced in this technique.

Methods. Twenty consultant vascular surgeons were divided into those who had performed > 50 endovascular procedures (e.g. aortic and carotid stent) as primary operator (n = 8), and those having performed < 10 procedures (n = 12). To test for endovascular skill rather than procedural knowledge, all subjects performed a renal artery balloon angioplasty and stent procedure. The simulator uses real tools with active force feedback, and provides a realistic image of the virtual patient. Surgeons with endovascular skills performed two repetitions and those without completed six repetitions of the same task. The simulator recorded time taken for the procedure, the amount of contrast fluid used and total fluoroscopy time.

Results. Initially, surgeons with endovascular skills were significantly faster (median 571.5 vs. 900.0 s, p = 0.039) and used less contrast fluid (19.1 vs. 42.9 ml, p = 0.047) than inexperienced operators, though differences for fluoroscopy time were not significant (273 vs. 441 s, p = 0.305). Over the six sessions, the inexperienced group made significant improvements in performance for time taken (p = 0.007) and contrast fluid usage (p = 0.021), achieving similar scores at the end of the training program to the experienced group.

Conclusions. Surgeons with minimal endovascular experience can improve their time taken and contrast usage during short-phase training on a VR endovascular task. VR simulation may be useful for the early part of the learning curve for surgeons who wish to expand their endovascular interests.

Keywords: Virtual reality; Simulation; Training; Endovascular skills; Curriculum.

Introduction

Minimally invasive techniques have become the gold standard for a number of general surgical procedures.1,2 This situation is now being applied to vascular diseases, with an increased number of procedures performed using an endovascular approach.3,4 The benefits include decreased morbidity, reducing length of hospital stay and an earlier return to daily activities.5 A feature of all endovascular procedures is the need to manipulate a wire within a three-dimensional field, whilst viewing its position on a two-dimensional screen. The acquisition of these skills takes time, in accordance with a learning curve to attain a pre-defined level of proficiency.6 The traditional apprenticeship mode of skill acquisition of graded practice on patients is effective, though perhaps not efficient. A new training tool is now available, which enables inexperienced operators to learn wire-handling skills without risk to patient safety. This involves the use of virtual reality (VR) simulation, in the same manner to the aviation model of training.

The benefits of VR simulation are the possibility to train in an educationally-orientated environment free of the time and cost pressures of learning new skills in the clinical arena.7 The trainee can also be mentored through the case, stopping as necessary to explain difficult parts of the procedure. The VR simulation can also provide an objective assessment of performance, facilitating the opportunity to provide formative and summative feedback regarding technical skills.8 This data can then be used to develop a training programme which is completed upon the demonstration of pre-defined levels of proficiency.9 It is thus possible to ensure that all trainees have attained pre-requisite levels of skill prior to progressing to
the interventional laboratory to refine their skills on patients.

The aim of this study was to assess the role of a virtual reality simulator for interventional vascular procedures (Vascular Interventional Surgical Trainer, Mentice Corporation, Gothenburg, Sweden). Firstly, we aimed to define whether the simulator was a valid and reliable tool for assessment of endovascular skills, and secondly to assess whether training on the simulator could lead to an improvement in the skills of inexperienced operators.

Methods

Subjects

Twenty surgeons with extensive experience in open vascular surgical procedures (>100 cases) were recruited to the study. They were then divided into two groups, based upon their experience in endovascular procedures. Eight of the surgeons had performed >50 endovascular procedures (e.g. aortic and carotid stent) as primary operator. The remaining 12 surgeons had limited experience in endovascular techniques (<10 procedures). Ethics approval was not necessary for this study, though all surgeons provided informed consent prior to commencement of the trial.

Simulation device

The VR simulator comprises an interface device, a high-performance desktop computer and two display screens (Fig. 1). The interface device is designed to be the virtual patient, with a simulated femoral approach to the vascular system. The subject begins the procedure by selecting the specific tool(s) to be used during the simulation from a number of on-screen options on the left-hand screen. A non-specific guidewire, catheter, balloon or stent system can then be inserted into the user interface, and a fluoroscopic image is subsequently displayed on the right-hand screen, together with the virtual tool which has been selected. The simulator consists of modules for angioplasty and stent of renal, carotid, coronary, iliac and femoral vessels. Each module contains a number of simulations derived from real patient data, which have been scanned from their CT images. Each simulation thus has a differing level of complexity, making it possible to define a step-wise approach to acquisition of endovascular skill.

Task performed

To test for endovascular skill rather than procedural knowledge, all subjects performed a non-ostial left renal artery balloon angioplasty and stent procedure. At commencement of the study, all subjects were familiarised to the VIST simulator and the task they had to perform. During the study, passive assistance was provided, though hands-on assistance was not allowed. All subjects completed the sessions within 2 days, with a maximum of three sessions per day for the inexperienced group. Furthermore, there was at least a 1 h break between consecutive sessions.

Performance evaluation

The VR simulator calculates metrics regarding performance at the end of each task, which can be downloaded into a spreadsheet for statistical analysis. The metrics used for this study for each session were

Fig. 1. The VIST simulator (Mentice Corporation, Gothenburg, Sweden).
total time taken, total amount of contrast fluid used and fluoroscopy time. In order to evaluate the use of this task for assessment of endovascular skill, all 20 subjects performed two repetitions of the renal artery angioplasty and stent procedure. Comparison of performance on the first two sessions between the two groups of subjects can assess whether the simulated task is construct valid, i.e. measuring the trait one purports it to measure. This can then substantiate the use of the simulator as a tool to assess endovascular technical skill. The inexperienced subjects performed a further four sessions on the simulator, totalling six in all. This enabled the charting of a learning curve, and clarifies whether repeated practice improves performance toward that of the experienced group. Finally, the definition of benchmark criteria to be achieved prior to progression onto the next stage of the curriculum was by calculation of the score for each parameter when performed by the eight surgeons with experience in endovascular procedures.

**Statistical analysis**

Data was analysed with the Statistical Package for the Social Sciences version 11.5 (SPSS, Chicago, Illinois, USA) using non-parametric tests. Comparison of performance between expert and novice groups was undertaken using the Mann–Whitney U-test. Data on learning curves was analysed by the Friedman (non-parametric repeated measures ANOVA) test. Multiple comparisons were then made to identify when plateau of skills had occurred. A level of \( p < 0.05 \) was considered statistically significant.

Comparing performances at the first session, there were no differences for any of the three measured parameters between the two groups of subjects. However, on the second session, the experienced group were significantly faster (median 571.5 vs. 900.0 s, \( p = 0.039 \)) and used significantly less contrast fluid (median 19.1 vs. 42.9 ml, \( p = 0.047 \)) to complete the task than the inexperienced group (Figs. 2 and 3). There were no statistically significant differences between the two groups for fluoroscopy time (273 vs. 441 s, \( p = 0.305 \)).

Over the six sessions, the inexperienced group made significant improvements in their performance for time taken (\( p = 0.007 \)) and contrast fluid usage (\( p = 0.021 \)), though there was no statistical improvement for fluoroscopy time (\( p = 0.187 \)). These
learning curves are shown graphically in Fig. 4 (time taken) and Fig. 5 (contrast fluid usage). The plateau phase for the learning curve occurred at the third repetition for both time taken and amount of contrast fluid used. By the end of the training program, those inexperienced in endovascular skills had similar performance parameters when compared to the experienced group, for time taken (571.5 s vs. 456 s, \( p = 0.491 \)) and contrast fluid usage (19.1 ml vs. 19.3 ml, \( p = 0.755 \)).

The lack of construct validity for the first session led to the definition of benchmark proficiency criteria to be based upon the performance of the experienced endovascular surgeons on their second session. These are taken from the median values for the two validated parameters of time taken (571.5 s) and amount of contrast fluid used (19.1 ml). For ease of reference, it is suggested that these are rounded up to 600 s and 20.0 ml, respectively.

**Discussion**

The recent surge in interest in endovascular techniques has led to a demand for training opportunities in the skills required to perform the procedure safely and effectively.\(^ {10} \) In tune with laparoscopy for general surgeons, the skills for endovascular manipulation are different to those required for open surgical procedures.\(^ {11} \) It is thus necessary to attain endovascular skills through a graded approach, in the presence of an experienced practitioner.\(^ {12,13} \) Currently this is performed by a vascular surgeon acquiring ‘wire skills’ by practicing procedures in the company of an experienced interventional radiologist. However, the surgeon is learning on a live patient, and the only benchmark used to qualify level of skill is ‘number of procedures performed’, inappropriately correlating experience with expertise. Furthermore, since the widespread introduction of magnetic resonance angiography, the traditional training opportunities offered by diagnostic angiograms have reduced in number.

This study has shown a vascular interventional virtual reality simulator to be a valid tool for both assessment and training in endovascular skills. All participants practiced a task, which they had not performed previously. The task revealed significant differences between those vascular surgeons with and those without experience in endovascular procedures. With training, the inexperienced group managed to improve to the level of those experienced in ‘wire skills’, as measured by the simulator. However, this study noted a lack of construct validity for fluoroscopy time—this may be due to the subjective observation that some of the experts maintained fluoroscopy for the majority of the procedure.

Apart from a handful of commentaries, review articles and editorials,\(^ {14–17} \) there are only two currently published papers which have sought to assess the validity of a virtual reality vascular interventional simulator.\(^ {18,19} \) Dayal et al. compared the performance of 16 general surgery residents (<5 cases) with that of five vascular surgeons who were experienced in endovascular procedures (>300 cases).\(^ {20} \) The subjects completed the carotid angioplasty and stenting module, followed by 2 h of training on the simulator. By the end of the training period, though all had improved, the inexperienced group did not manage to achieve expert levels of skill. This may be due to the fact that the carotid module is more technically challenging than the renal simulation, and also because of the massed nature of the training program. A study by Hsu et al. similarly assessed the construct validity of the carotid module on this simulator, and the relative improvements in skill following 30–60 min of training.\(^ {21} \)

It must though be noted from our study that even the experienced endovascular practitioners required one session to familiarize with the simulator. This is important, as it is only with the second session that it is a true assessment of endovascular skill, rather than a test of how quickly one adapts to a new tool. It would have been desirable to assess the performance of the experienced group on a total of six sessions, to confirm the earlier plateau of their learning curve. However, this was not possible due to timing constraints.

As the learning curve for the inexperienced group plateaued at the third session, it also seems that they require just one session more than the experienced group to reach the same skills level. This may be
because of the surgeons in the experienced group were not truly experts, or that the tasks on the simulator are too easy. It is thus our aim to follow-up this study with an assessment of the skills of interventional radiologists on the same tasks, and compare their performance with that of the experienced group of vascular surgeons. Though plateau of the inexperienced group was at the third session, the variability within the group continued to decline, suggesting that many of the individuals continued to improve their skills. This illustrates the need to define benchmark levels of skill, rather than numbers of trials performed, to ensure that all members of the group have achieved the proficiency level.

The demographic differences between groups were unfortunately not collected, and would have provided interesting comparisons. This is especially true when discussing the proposition of whether vascular surgeons with laparoscopic skills would have a shorter learning curve for the acquisition of endovascular skills when compared with an equivalent group who do not regularly perform laparoscopy. Both procedures involve manipulation in three dimensions of an instrument, which is viewed on a two-dimensional screen, with reduced force feedback. There is published work, which confirms the existence of a relationship between the laparoscopic and endoscopic skills of surgeons performing tasks on endoscopic and laparoscopic virtual reality simulators. We thus intend to investigate whether a similar relationship exists between laparoscopic and endovascular skill.

From the results of our study, it is possible to define the first step in an endovascular skills training curriculum, with evidence-based benchmark criteria to achieve. In the future it will be important to assess performance not only on time taken and contrast fluid usage, but also on potentially more clinically relevant parameters such as appropriateness of balloon and stent sizing, accuracy of stent placement and remnant stenosis. The eventual aim is to use VR simulation technologies to shorten the learning curve for achievement of proficiency on real cases, in an analogous manner to the aviation industry.

Another potential benefit of virtual reality simulation is the ability to process real patient data from a CT scan, and enable the interventionalist to practice the ‘real’ case on the simulator, prior to performing the real case on the patient. Any tricky or difficult parts of the procedure can be repeated, reducing the likelihood of real errors or adverse events occurring due to technical difficulties. VR simulation may also be used to provide realistic tests of new instruments or tools, which have yet to come to market. Use of a VR simulator also does not involve any ionizing radiation, and can enable healthcare personnel to practice without exposure to such risks.

In summary, this virtual reality simulator is a feasible, valid and efficacious training tool for vascular surgeons who are interested in developing their endovascular skills. However, we believe the overall approach to training must be graded, and provided within a structured curriculum, rather than over short training courses. We have shown an improvement in skill for a renal procedure, but the attainment of proficiency to perform a more complex procedure will take more time. Integral to this curriculum is the incorporation of didactic sessions for knowledge-based learning, and observation with graded practice in the interventional suite. The benefit of instant objective feedback of performance also makes it possible to ensure that proficiency is achieved prior to progressing onto the next stage of the training curriculum, and indeed prior to performing cases on patients. This is the basis of a competency-based training curriculum and can lead toward the ultimate goal to improve patient safety through a reduction in the number of unnecessary errors and adverse events.

References

Virtual Reality Endovascular Skills Training


17 Klein LW. Computerized patient simulation to train the next generation of interventional cardiologists: can virtual reality take the place of real life? Catheter Cardiovasc Interv 2000;51:528.


Accepted 8 November 2005
Available online 4 January 2006