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Identification of Skills Common to Renal and Iliac Endovascular Procedures Performed on a Virtual Reality Simulator

S.K. Neequaye,[1,2]* R. Aggarwal,[1] R. Brightwell,[1,2] I. Van Herzeele,[1,2] A. Darzi[1] and N.J.W. Cheshire[1,2]

[1]*Department of Biosurgery and Surgical Technology, Imperial College, London, UK, and* [2]*Regional Vascular Unit, St. Mary's Hospital, London, UK*

Introduction. *There is a learning curve in the acquisition of endovascular skills for the treatment of vascular disease. Integration of Virtual reality (VR) simulator based training into the educational training curriculum offers a potential solution to overcome this learning curve. However evidence-based training curricula that define which tasks, how often and in which order they should be performed have yet to be developed. The aim of this study was to determine the nature of skills acquisition on the renal and iliac modules of a commercially-available VR simulator.*

Method. *20 surgical trainees without endovascular experience were randomised to complete eight sessions on a VR iliac (group A) or renal (group B) training module. To determine skills transferability across the two procedures, all subjects performed two further VR cases of the other procedure. Performance was recorded by the simulator for parameters such as time taken, contrast fluid usage and stent placement accuracy.*

Results. *During training, both groups demonstrated statistically significant VR learning curves: group A for procedure time ($p < 0.001$) and stent placement accuracy ($p = 0.013$) group B for procedure time ($p < 0.001$), fluoroscopy time ($p = 0.003$) and volume of contrast fluid used ($p < 0.001$). At crossover, subjects in group B (renal trained) performed to the same level of skill on the simulated iliac task as group A. However, those in group A (iliac trained) had a significantly higher fluoroscopy time (median 118 vs 72 secs, $p = 0.020$) when performing their first simulated renal task than for group B.*

Conclusion. *Novice endovascular surgeons can significantly improve their performance of simulated procedures through repeated practice on VR simulators. Skills transfer between tasks was demonstrated but complex task training, such as selective arterial cannulation in simulators and possibly in the real world appears to involve a separate skill. It is thus suggested that a stepwise and hierarchical training curriculum is developed for acquisition of endovascular skill using VR simulation to supplement training on patients.*

Keywords: Computer simulation; Vascular surgical procedures; Interventional radiology; Motor skills.

Introduction

Vascular disease is a common and growing problem in aging western populations.[1] Endovascular treatment options are associated with reduced mortality and length of hospital stay compared to open surgery.[2] Endovascular treatment of vascular disease is increasingly popular with both patients and healthcare providers.[3,4] The increase in endovascular treatment has led to growing interest in endovascular training for vascular surgeons.[5,6] Limited working hours and the increasing application of non-invasive imaging techniques are a barrier to endovascular skills training for vascular surgeons.[7] Modern virtual reality simulation devices have the potential to allow both training and assessment outside the interventional suite with potential benefits for patient safety.[8]

Virtual reality (VR) refers to the creation by computer of a predominantly visual environment, with or without haptic feedback (tactile interaction and feedback).[9] VR simulation allows training in a safe and educationally oriented environment.[10] High fidelity VR endovascular simulators are commercially available that allow a trainee to improve psychomotor skills performance on the simulator by repeated practice of a procedure or manoeuvre.[11] Simulator derived data such as fluoroscopy time and volume of contrast used have been claimed by some workers to have construct validity, with the ability to distinguish between

*Corresponding author. Mr Simon Neequaye, Department of Biosurgery and Surgical Technology, Imperial College, St Marys Hospital, Praed Street, London, UK.
E-mail address: s_neequaye@yahoo.com

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different levels of skills performance in a small number of recent studies.[11–14] Others have pointed out that limitations in these studies such as the use of surrogate endpoints (e.g. fluoroscopy time) need to be addressed before reliable skills assessment becomes possible with identification and incorporation of more appropriate metrics into the endovascular training curriculum.[15]

Initial work on VR endovascular training has focused on device validation, but if these devices are to be used in training programmes we also need to know how to put the different modules together to form part of a coherent, structured, proficiency-based and deliverable skills training programme. VR endovascular trainers have multiple modules with tasks of varying complexity. In order to establish an evidence base for training on the different modules of VR simulators there is a need to determine which tasks should be performed, how many repetitions are required and in what order they should be performed. The number of repetitions required to achieve proficiency depends on the aptitude of the individual trainee as well as the training curriculum and the simulator itself. A significant and variable amount of training may be required to achieve maximal benefit, standards which define performance-based endpoints need to be established.[16]

Skills performance in general improves following a period of training with the rate of improvement slowing as the learning curve reaches a plateau. This study was designed to establish the learning curve of surgeons performing VR endovascular tasks and to provide information with regards to the transfer of skills between different simulator tasks. In particular, whether psychomotor skills gained are specific to a given simulator task or whether generic endovascular skills are gained that allow improved performance on other simulated skills tasks. Future demonstration of construct validity and of transfer of training from VR simulators to procedures in patients will help to support curricula for endovascular skills training.

Methods and Materials

Subjects

Twenty surgeons with no previous endovascular experience were randomised into two equal groups of ten using sealed envelopes. One group was assigned to training Protocol A, and the second to Protocol B (Fig. 1).

Simulator device

The Simulation device used was the Vascular Intervention System Training simulator (VIST, Mentice Corporation, Gothenderg, Sweden). This is a part task virtual reality device as arterial puncture and closure are not involved. The Simulation software uses reconstructions based on real contrast enhanced CT scans and force feedback i.e. a haptic interface giving tactile feedback. The subject interacts with the simulation through a femoral access point admitting modified guidewires and catheters with separate controls for simulated stent deployment, balloon inflation and contrast material injection. Fluoroscopic imaging is simulated using a foot pedal and the user interface functions allow table movement, C-arm positioning, catheter and wire selection as well as recording cineloops and construction of roadmaps.[11] Different simulation modules allow the user to perform endovascular interventions in carotid, coronary, renal, iliac and femoral vessels. Each module contains a number of simulations of differing levels of complexity making it possible to define a step-wise approach to skills training.[13]

Simulator tasks

Two simulator tasks were used for training, i.e. Task 1 iliac angioplasty and task 2 renal angioplasty. A right common iliac angioplasty procedure performed via an ipsilateral femoral access point and a left non-ostial renal artery lesion via the contralateral right femoral artery. These particular tasks were chosen because the ipsilateral iliac angioplasty task requires the subject to perform a diagnostic angiogram followed by accurate stent placement. The renal angioplasty module (Task 2) also entails performance of an angiogram and accurate stent deployment, following selective cannulation of the renal artery. Ability in simulators to selectively cannulate a target artery has been demonstrated to correlate with endovascular expertise though also with the number of video game hours played per week.[14] Performance of the renal task was therefore added as a further step to present a more demanding and potentially discriminatory technical task.

Group A

To evaluate the learning curve of surgeons performing an iliac artery angioplasty on the iliac module, group A ($n = 10$), performed 8 repetitions on the iliac module (Task 1) following a demonstration of the procedure by the investigator. To assess transfer of skill to

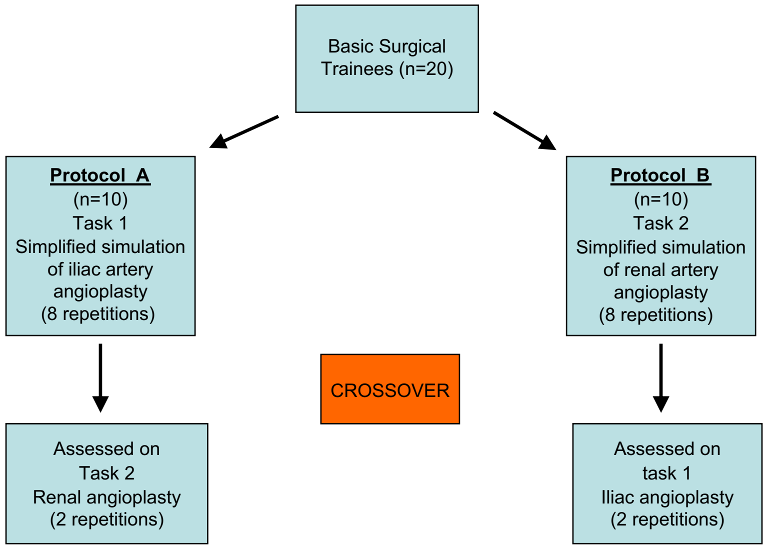

Fig. 1. Study protocol design.

the renal task, subjects were then assessed performing 2 renal artery angioplasty procedures following a demonstration (Task 2).

Group B

The second Group of ten were assigned to the opposite protocol. In protocol B subjects ($n = 10$) were assessed performing 8 repetitions on the renal module (Task 2) following a demonstration of the procedure by an investigator. Finally this group who were trained on the renal module completed 2 runs on the iliac module following a demonstration (Task 1).

In order to allow comparison the tools used were standardised and all participants were provided with a written step by step guide of each procedure which was available to view at all times (Fig. 2). The instructor was required to select appropriate tools as specified in the study protocol and perform all functions related to running of the simulator. Road-mapping and table positioning were also controlled by the instructor. This level of assistance might have introduced investigator bias but was felt to be necessary because this was a novice group of subjects in part; but also because the main aim of this study was to assess technical skill and not the cognitive factors required in selecting tools or choosing an appropriate table position. The instructor was therefore only allowed to offer passive assistance and was not allowed to handle tools once inserted or give any help or advice during the study.

Data collection

Demographic data was collected using a pre-procedure questionnaire. Performance related data was recorded automatically for all 10 runs for each subject by the simulator. Metric data collected in this study were procedure time, fluoroscopy time, contrast fluid used, placement accuracy, residual stenosis, lesion coverage, stent-vessel ratio and stent deployment pressure.

Any step missed from the procedure protocol (which was available to view at all times) was counted as an error.

Statistical analysis

Data was analysed using the Statistical Package for the Social Sciences version 13.0 (SPSS, Chicago, Illinois, USA) using non-parametric tests. The learning curve data did not conform to a normal distribution and was therefore analysed by multiple comparisons using the Friedman (non parametric repeated measures ANOVA) test. Multiple comparisons were made to identify when plateau of learning had occurred. A level of $p < 0.05$ was considered statistically significant. Comparison of performance between the two groups following crossover to the second task was performed using the Mann-Whitney U-test.

Results

The groups were similar in terms of demographics (Table 1).

Task 1 (Simplified simulation of common iliac artery angioplasty and stenting procedure)

- Introduce 0.035 inch guidewire into aorta
- Introduce Diagnostic Catheter into aorta over guidewire
- Inject Contrast to perform angiogram
- Exchange diagnostic catheter for guide catheter
- Your instructor will construct a roadmap for you
- Pass 0.014 inch guidewire into aorta past stenosis
- Introduce balloon mounted stent over the wire
- Centre the stent within the lesion (stenosis) using radio opaque markers to guide you
- Inflate balloon to 12 ATM
- Remove stent system
- Perform completion angiogram

Task 2 (Simplified simulation of left renal artery and stenting procedure)

- Introduce 0.035 inch Guidewire into Aorta
- Introduce Diagnostic Catheter into Aorta over guidewire
- Inject Contrast to perform angiogram
- Exchange diagnostic catheter for guiding catheter
- Cannulate renal artery using roadmap which your instructor will construct for you
- Pass 0.014 inch guidewire into renal artery past stenosis
- Introduce balloon mounted stent over the wire
- Centre the stent within the lesion (stenosis) using radio opaque markers to guide you
- Inflate balloon to 12 ATM
- Remove stent system
- Perform completion angiogram

Fig. 2. Subject Instruction Sheet.

Metric data collected in this study were procedure time (PT), fluoroscopy time (FT), contrast fluid used (CF), placement accuracy (PA), residual stenosis (RS), lesion coverage (LC), stent-vessel ratio (SVR) and maximum stent deployment pressure (MP).

Learning curve

Over the eight sessions both groups demonstrated improvements in performance. For Task 1 (Iliac) significant VR performance improvement was demonstrated for procedure time (median 357 vs 142 s, $p < .001$) and placement accuracy (2.1 vs 1.3 mm, $p = 0.013$). No significant improvements were observed for volume of contrast fluid used and fluoroscopy time though a similar trend was noted with reduced use of contrast fluid (10.1 vs 6.15 mls, $p = 0.419$) and fluoroscopy time (119.5 vs 60.5 $p = 0.1$). For Task 2 (Renal), significant improvements were demonstrated in procedure time (411 vs 180 s, $p < .001$), fluoroscopy time (163 vs 112.5 s, $p = 0.003$) and contrast fluid used (13.7 vs 8.25 mls, $p < .001$). These learning curves are demonstrated graphically for procedure time Fig. 3 (iliac) and Fig. 4 (renal), fluoroscopy time Fig. 5 (Iliac) and Fig. 6 (renal) and volume of contrast fluid used Fig. 7 (iliac) and Fig. 8 (renal).

The plateau phase for the learning curve in Task 1 occurred after the fourth repetition for placement accuracy ($p < 0.05$, Friedman test); procedure time continued to improve significantly up to the eighth and final repetition and did not reach plateau ($p > 0.05$). For Task 2, the plateau in performance was after the third repetition for procedure time and contrast fluid used ($p < 0.05$) and the fifth repetition for fluoroscopy time.

Table 1. Group demographics

	Group A	Group B
Number	10	10
Age, years (median, range)	29 (26–32)	29 (25–34)
Grade		
Senior House Officer	7	7
Registrar	3	3
Endovascular experience		
None	5	6
Observed	5	4
Performed	0	0

Crossover

At crossover, performance of group A on the renal module was compared to the final two training runs of group B. Likewise performance of group B on the iliac module was compared to the final two training runs of group A.

For the task 1 (iliac) there was no difference in performance between the two groups (Table 2, 3).

For the task 2 (renal), fluoroscopy time was significantly lower in group B, (median 72 vs 118 seconds, $p = 0.020$) (Table 4, 5).

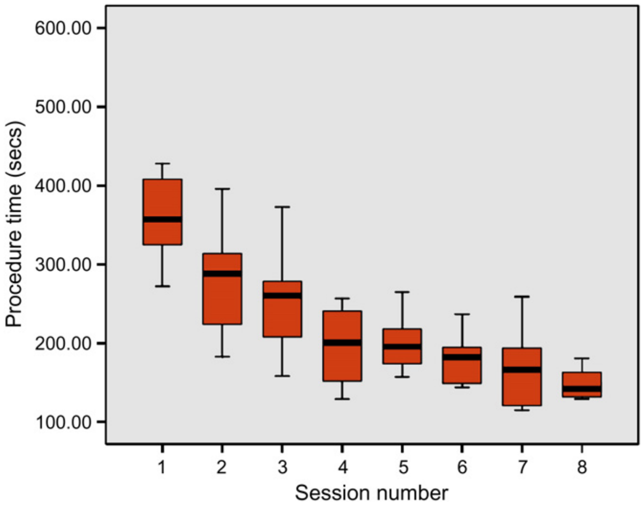

Fig. 3. Learning curve for Task 1 (iliac) for procedure time $p < .001$ (Friedman test).

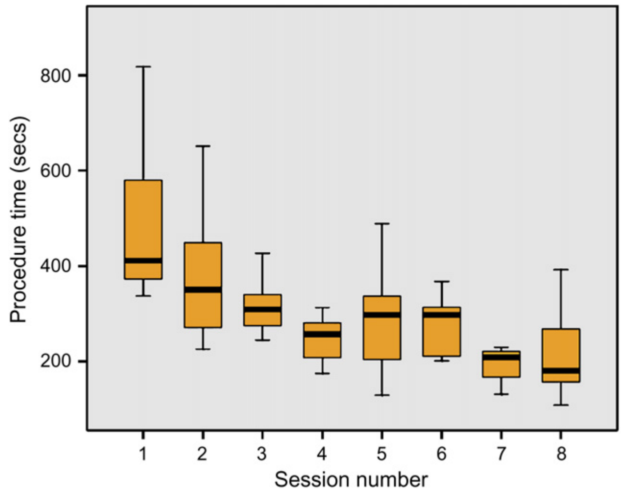

Fig. 4. Learning curve for Task 2 (renal) for procedure time. $p < .001$ (Friedman test).

Error scores

Any step omitted from the subject instruction sheet was considered an error. The number of steps omitted for each procedure was totalled on the basis of the procedure report provided by the simulator. There were no differences in number of steps omitted by the two groups during training or crossover. In fact, median number of steps omitted was 0 for each group with only 7 omitted steps recorded in both groups.

Discussion

Invasive procedures such as endovascular interventions carry the risk of significant harm to patients. Practitioners display a procedure related learning curve as demonstrated by outcomes in sequential groups of patients undergoing carotid artery stenting. This reveals a higher incidence of procedure-related complications in particular stroke early on in the learning curve.[17] Whilst training on real patients is an unavoidable consequence of medical training it is necessary to protect patients from harm where possible. Currently, supervised training with progressive exposure to procedures is the norm.

This study has demonstrated the VR learning curve for novice surgeons performing endovascular skills tasks using a commercially available high fidelity VR simulator. The plateau in skills performance on the simulator occurred at the 4th and 3rd session for

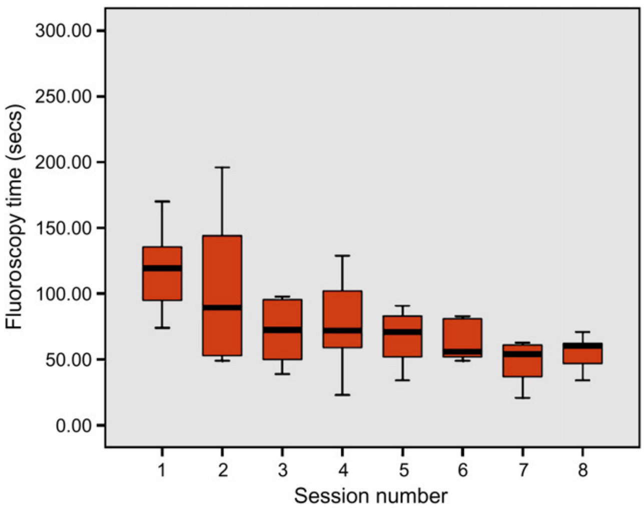

Fig. 5. Learning curve for Task 1 (iliac) for fluoroscopy time. $p = 0.1$(Friedman test).

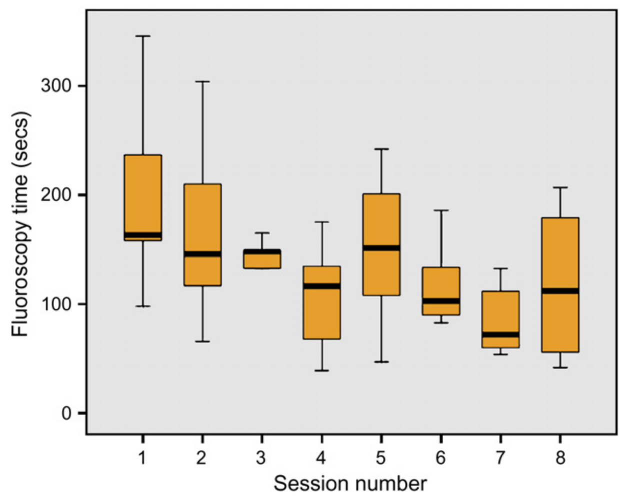

Fig. 6. Learning curve for Task 2 (renal) for fluoroscopy time. $p = 0.003$ (Friedman test).

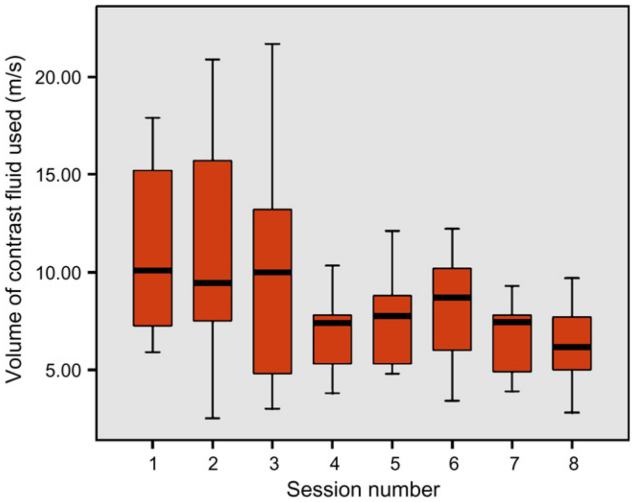

Fig. 7. Learning curve for Task 1 (iliac) for volume of contrast fluid used. $p = 0.419$ (Friedman test).

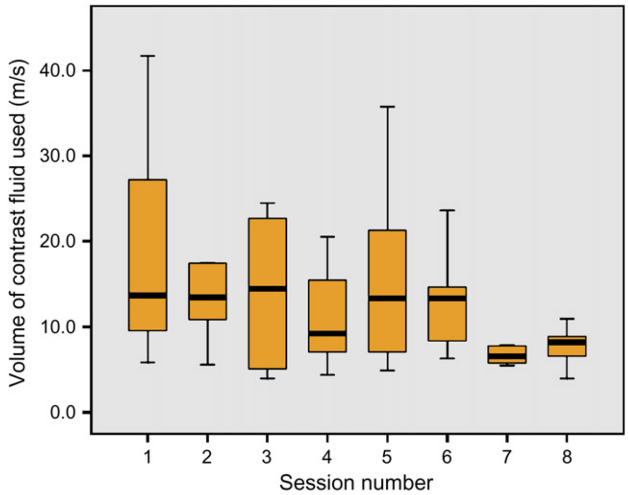

Fig. 8. Learning curve for Task 2 (renal) for volume of contrast fluid used. $p < .001$ (Friedman test).

task 1 and 2 respectively. This finding is supported by the reduction in the range of results for both groups towards the end of training.

Skills transfer across the iliac and renal modules of the VIST simulator was assessed by crossover of the two training groups. Group B performed to an equivalent level on the iliac task as group A. This suggests that endovascular skills were learned by group B that enabled performance on the simulated iliac task to a comparable level to subjects who had undergone repetitive practice on that task. For the simulated renal task fluoroscopy time was significantly lower in group B than the group A at crossover. This may indicate that group B who were trained on the renal module had learned a skill specific to the renal artery task and did not require as much fluoroscopy time to achieve cannulation of the renal artery. This skill was specific to the renal artery task and suggests that task specific training may have occurred. However there was no difference in overall procedure time or accuracy of stent deployment and it must be noted that potentially confounding factors such as video games experience and knowledge were not assessed. Time to achieve selective cannulation of a target vessel has been demonstrated to differentiate endovascular skill using a VR endovascular trainer; though this group also found a correlation with video games experience.[13] This method of skills assessment, so called time-action analysis may have better answered this question and should be considered in future studies that address this question.[18]

The benefit of training outside the operating theatre is well established in other surgical fields such as laparoscopy with a number of studies demonstrating the positive effects of specific skills training on subsequent performance using bench models and Virtual reality.[19,20] This so called transfer of training has not been well reported in the literature with regards to endovascular skills i.e. demonstration of positive skills transfer from VR training to real life though results

Table 2. Post training performance on iliac artery module

Metric	Run 7 iliac (Group A)	Run 1 iliac (Group B)	MWU
PA (mm)	3.4	2	0.344
RS (%)	20	40	0.210
LC (mm)	100	100	0.317
SVR	.81	.6	0.210
MP-target (mm Hg)	4.08	2.08	0.112
PT (s)	167	176	0.406
CF (ml)	7.5	6.15	0.791
FT (s)	54	59	0.273

Run 7 of group A (iliac training) vs run 1 of group B (renal training). Median values and p value with Mann Whitney U.
[Placement Accuracy-PA, Residual stenosis-RS, Lesion coverage-LC, Stent to vessel ratio-SVR, Maximum pressure-MP, Procedure time-PT, Contrast fluid-CF, Fluoroscopy time-FT].

Table 3. Post training performance on iliac artery module

Metric	Run 8 iliac (Group A)	Run 2 iliac (Group B)	MWU
PA (mm)	1.3	2.5	0.140
RS (%)	27	41	0.241
LC (mm)	100	100	1.0
SVR	.73	.6	0.241
MP-target (mm Hg)	3.32	1.36	0.496
PT (s)	142	143	0.596
CF (ml)	6.15	6.6	0.705
FT (s)	60.5	55	0.186

Run 8 of group A (iliac training) vs run 2 of group B (renal training). Median values and p value with Mann Whitney U.

Table 4. Post training performance on renal artery module

Metric	Run 7 renal (group B)	Run 1 renal (group A)	MWU
PA (mm)	2.7	1.3	0.120
RS (%)	7	5	0.546
LC (mm)	100	100	0.607
SVR	.93	.95	0.391
MP-target (mm Hg)	3.16	3.6	0.549
PT (s)	209	228	0.191
CF (ml)	6.6	7	0.513
FT (s)	72	118	0.02**

Run 7 of group B (renal training) vs run 1 of group A (iliac training) on renal module. Median values and *p* value with Mann Whitney U.

Table 5. Post training performance on renal artery module

Metric	Run 8 renal (group B)	Run 2 renal (group A)	MWU
PA (mm)	2.2	1.5	0.486
RS (%)	2	31	0.581
LC (mm)	100	100	0.292
SVR	.995	.7	0.806
MP-target (mm Hg)	2.08	2.68	0.774
PT (s)	180	219	0.624
CF (ml)	8.25	6.7	0.902
FT (s)	113	139	0.540

Run 8 of group B (renal training) vs run 2 of group A (iliac training) on renal module. Median values and *p* value with Mann Whitney U.

of the first randomised trial suggests such a benefit following VR endovascular skills training.[21]

This is the first study that has demonstrated transference of skills between VR endovascular skills tasks. We have demonstrated that deliberate practice of skills in one anatomical part of the simulation can improve skills that are common to another part. Performance of the simulated renal catheterisation task seems to have shown that additional skill(s) (cognitive or psychomotor) are required for success in this part of the simulation. It appears that to some extent the VR endovascular skills trainer used in this study is able to provide skills that are common to different modules. However this is a simulation based study and these results should be interpreted in this context. It is necessary to corroborate the results of simulator based studies such as this with results in the clinical domain.

Though we have shown that surgeons with no previous endovascular experience can improve their skills using VR based simulation there are a number of limitations in this study. The subjects recruited may not have been representative sample of all trainees. Aptitude of individual subjects was not assessed because the statistical analysis was based on grouped data and whilst it is desirable and important to analyse individual learning curve data this was not the aim of this study. The definition of aptitude in terms of rates of learning new skills is a new area of research, currently in its infancy. Error scores have been suggested as discriminators of skill.[22,23] We did not demonstrate an improvement in error scores following training though the definition of an error as a missed procedure step may have been too simplistic, particularly as the procedure instruction sheet was visible to participants at all times. Procedure time continued to improve for group A up to the 8th and final training session- procedure time may have continued to improve if further sessions were available however this was not part of the original study design. Moreover, faster procedure time alone is recognised to be a poor indicator of technical skills[24] and may reflect the inexperience of this novice group of subjects performing in an arena with no perceived risk of adverse outcome. This is a limitation of simulator based training where training in the absence of consequences may teach and reinforce bad habits.[25] The simulator derived metric data used in this study are surrogate markers of skills performance and must be interpreted as such.

VR endovascular simulators have been proposed as tools for training and assessment in vascular surgery; however a great deal of work on the development and validation of interventional radiology procedural simulations must be completed before the inclusion of simulations on board and or other statutory certification examinations can be endorsed.[8] Evidence based training curricula defining which tasks, in what order and how many repetitions should be performed is lacking. We believe that the findings of this study show that VR training can play a role in endovascular skills training. Further work is required in terms of device validation and determination of what constitutes expert levels of performance. There are a number of such studies currently being performed including pilot studies by the SIR (Society of Interventional Radiology), CRF (Cardiovascular Research Foundation) and ABIM (American Board of Internal Medicine). In addition to device validation studies we believe that it is also necessary to examine the process of simulation based training. The results of this study suggest that there is some crossover between simulator modules, it may therefore not be necessary for endovascular novices to complete all of the available simulation modules. It may be better perhaps to train to a benchmark level of performance at core skills rather than a set number of repetitions or time.[9,10] Indeed using high fidelity simulations to train novice subjects may not be appropriate. If the aim is to become proficient at basic catheterisation skills, simpler and cheaper models may be more suitable. Rather than developing increasingly advanced and therefore expensive simulations we believe that further studies are required to identify what constitutes core endovascular skill and how best to use available simulator technology to gain these skills.

Simulation based training should complement clinical training and may improve patient safety as the early part of an individual trainee's learning curve will take place within a dedicated training environment prior to exposure to patients. This may mitigate the effect of reduced training hours on skills training though a validated training curriculum has yet to be developed.

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