Cognitive training improves clinically relevant outcomes during simulated endovascular procedures

Isabelle Van Herzeele, MD,[a,b] Rajesh Aggarwal, MA, MRCS, PhD,[b] Simon Neequaye, BSc, MSc, MRCS,[b] Ara Darzi, KBE, MD, FRCS,[b] Frank Vermassen, MD, PhD,[a] and Nicholas J. Cheshire, MD, FRCS,[b,c] *Ghent, Belgium; and London, United Kingdom*

Objectives: **Virtual reality (VR) simulation has been suggested to objectively assess endovascular skills. The aim of this study was to determine the impact of cognitive training on technical performance of inexperienced subjects on a commercially available VR simulator (VIST, Vascular Intervention Simulation Trainer, Mentice, Gothenburg, Sweden).**
Methods: **Forty-seven subjects treated an identical virtual iliac artery stenosis endovascularly. Surgical trainees without endovascular experience were allocated to two training protocols: group A_1 (n = 10) received a 45 minute didactic session followed by an expert demonstration of the procedure that included error-based learning, whereas group A_2 (n = 10) was only given a demonstration of an iliac dilation and stent procedure. All trainees performed the intervention immediately following the expert demonstration. Twenty-seven endovascular physicians were recruited (>100 endovascular interventions). Performance was assessed using the quantitative (procedure and fluoroscopy time) and qualitative (stent/vessel ratio and residual stenosis) assessment parameters recorded by the simulator.**
Results: **The end-product (qualitative metrics) in the cognitive-skills group A_1 was similar to those of the endovascular physicians, though A_2 performed significantly worse than the physicians (group B): stent/vessel ratio (A_1 0.89 vs B 0.96, $P = .960$; A_2 0.66 vs B 0.96, $P = .001$) and residual stenosis (A_1 11 vs B 4%, $P = .511$; A_2 35 vs B 4%, $P < .001$). Group A_1 took longer to perform the procedure (A_1 982 vs B 441 seconds, $P < .001$), with greater use of fluoroscopy than group B (A_1 609 vs B 189 seconds, $P < .001$) whereas group A_2 performed the intervention as quickly as group B (A_2 358 vs B 441 seconds, $P = .192$) but used less fluoroscopy (A_2 120 vs 189 seconds, $P = .002$).**
Conclusion: **Cognitive-skills training significantly improves the quality of end-product on a VR endovascular simulator, and is fundamental prior to assessment of inexperienced subjects. (J Vasc Surg 2008;48:1223-30.)**

Over the last decades, surgical management of vascular disease has undergone tremendous change with the introduction, expansion, innovation, and evolution of catheter-based minimally-invasive interventions. Both vascular surgeons and patients have embraced endovascular therapy due to reduced pain, smaller scars, faster recovery, and shorter hospital stays. However, the advent of catheter-based interventions poses technical challenges to inexperienced surgeons as well as to trainers. Similar to general surgeons during the introduction of endoscopic and laparoscopic interventions,[1] operators need to learn how to manipulate an instrument (wire) within a three-dimensional field, whilst viewing its position on a two-dimensional screen,[2] they must deal with reduced tactile feedback and the increased need for hand-eye coordination.[3]

Learning of advanced technical skills has little or no meaning unless the surgeon also knows how and when to use these skills.[4,5] Fitts and Posner suggested that the learning process of complex skills is sequential and that we move through three specific phases while learning.[6] During the first stage (cognition), the trainee gains an insight into the task through instructor explanation and demonstration. Within the second stage (association), novices practice the task, associating these cognitive elements with musculoskeletal maneuvers to reduce errors, while the teacher provides feedback. The final phase (automation) occurs when the subject performs the task in an automated fashion, with little or no cognitive input.[7] Therefore, future peripheral vascular interventionalists must first possess the knowledge about vascular diseases and clinical judgment prior to performing minimally-invasive procedures.[8] Cognitive skills such as error detection, forward planning, and decision-making are crucial and need to be taught with didactic methodologies before a novice commences psychomotor-skills training.[9]

Current opportunities for future interventionalists to help translate cognition into motor behavior are limited by a number of factors including patient safety,[10] the reduction in length of residency programs, the regulation of "duty hours,"[11] and the increasing application of noninvasive diagnostic strategies.[12] The use of endovascular simulators may be an adjunct to traditional human hands-on training in basic wire and catheter handling skills.[13]

From the Department of Thoracic and Vascular Surgery, Ghent University Hospital,[a] Department of Biosurgery and Surgical Technology, Imperial College Healthcare NHS Trust, London,[b] Regional Vascular Unit, St. Mary's Hospital, London.[c]
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Correspondence: Dr Isabelle Van Herzeele, Clinical Research Fellow, Department of Thoracic and Vascular Surgery, Ghent University Hospital, 2K12 IC, De Pintelaan 185, 9000 Ghent, Belgium (e-mail: vhisabelle@gmail.com).
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There is good evidence that VR-skills training can improve wire skills in particular when used early in the trainee learning curve[2,3,14-17] and that the skills gained during simulation can be transferred to the in vivo model.[18,19] Repetitive practice using simulation allows surgical trainees as well as already trained surgeons to achieve proficiency in endovascular techniques prior to intervene on patients.[20] Indeed, the major advantage of simulator-based training is the facility to objectively assess technical skills performance, a required element for proficiency-based training.[21,22]

The aims of this study were twofold. The first aim was to assess the impact of cognitive-skills training on technical-skills performance of surgical trainees during a virtual endovascular iliac angioplasty and stent procedure. The second aim was to validate the assessment parameters of the iliac module of a commercially available simulator through comparison of the performance of surgical trainees to those of endovascularly experienced physicians.

METHODS

Subjects. Forty-seven subjects were recruited and assessed during endovascular treatment of a standardized simulated right common iliac artery lesion using an ipsilateral femoral artery access. The non-complex iliac module was chosen since trainees should not be allowed to perform complex endovascular procedures prior to obtaining basic generic endovascular skills. All subjects completed a questionnaire to assess their endovascular experience and prior usage of virtual reality (VR) simulators. Twenty junior surgeons (observed <10, 0 hands-on endovascular experiences) were recruited from a university teaching hospital. Twenty-seven physicians, who had performed at least 100 therapeutic endovascular interventions as the primary operator, were recruited at various international meetings and at the simulation laboratory of Imperial College, London. They were divided into two groups based upon their prior endovascular experience: an intermediate B_1 (>100 <300 endovascular procedures; n = 8) and highly experienced group B_2 (>300; n = 19).

Simulation device. The virtual reality simulator (VIST, Mentice, Gothenburg, Sweden) is a part task VR device as arterial puncture and closure are not involved. The system consists of a standard desktop personal computer and two flat-panel monitors coupled to a mechanical interface device (haptics unit) that allows the user to insert and manipulate standard wires, catheters, balloons, and stents. The interface device is designed to be the virtual patient with a simulated groin. The subject starts the procedure by selecting specific tool(s) to be used during the simulation, inserts this into the user interface and a fluoroscopic image (activated with a foot pedal) is subsequently displayed together with the virtual tool which has been selected. Separate controllers for simulated stent deployment, balloon inflation, and contrast material injection are provided. User interface functions include table movement, fluoroscopic C-arm positioning, cine-loop recording, and road mapping. Different simulation modules of differing levels of complexity allow the user to perform endovascular interventions in carotid, coronary, renal, iliac, and femoral vessels with differing complexity.

Simulated iliac procedure. At the commencement of the study, a standardized brief introduction to the VR simulator was delivered to all subjects. Following this, the available endovascular materials and the patient's case summary showing the iliac lesion were explained. During the simulated iliac procedure, passive assistance was provided by an interventional team: assistant, radiographer, circulating nurse. This study aimed to test the endovascular skills rather than procedural knowledge, therefore, a protocol was available explaining the different steps of a simulated iliac procedure for all subjects (Table I, online only). Appropriate endovascular tools were selected when asked for and orientation of the C-arm was modified as requested. A ruler was available but could not be moved and, therefore, only provided a crude measure of distance.

Cognitive-skills training. The novices were allocated (not randomized) into two consecutive groups of ten (Fig 1). Both groups were asked to perform the simulated assessment task following a standardized demonstration by an experienced physician of the different endovascular tools and steps during the virtual iliac angioplasty and stent procedure. However, group A_1 were first provided with a 45-minute one-to-one didactic training session during which indications for treatment, relevant vascular anatomy, steps of an iliac procedure, dangers of fluoroscopy (radiation of patient and interventional team), potential errors, pitfalls, and complications occurring during endovascular treatment of iliac stenosis were emphasized. The theory explained in the didactic session was turned into practice during the more extensive demonstration by the expert on the VR simulator in this cognitive-skills group: fluoroscopy usage, instructions about guidewire manipulation, correct vessel selection, catheter exchange, and angioplasty and stenting were explained and errors were again emphasized. Ethics approval was not necessary for this study, though all participants provided informed consent.

Performance evaluation. The VR simulator assesses performance by recording quantitative and qualitative metrics objectively and instantly. The quantitative metrics recorded for this study were procedure time, contrast volume, and fluoroscopic time. The qualitative metrics registered by the VR simulator were clinical parameters: placement accuracy of stent or balloon (millimeters), lesion coverage by the balloon or stent (%), balloon/vessel ratio (range, 0-1.2), stent vessel ratio (range, 0-1.2) and residual stenosis (%). A stent/vessel ratio of <1 indicated an undersized stent, >1 an oversized stent, and 1 a perfect stent choice for the treated vessel. Error scoring was not available for this module and errors did not cause any complications, eg, oversizing of a stent did not result into rupture of the artery. At the end of each task, a performance report was available which could be used for further analysis.

Statistical analysis. Data were analyzed with the Statistical Package for the Social Sciences version 15.0 (SPSS, Chicago, Ill). Owing to the nature of the data (which were

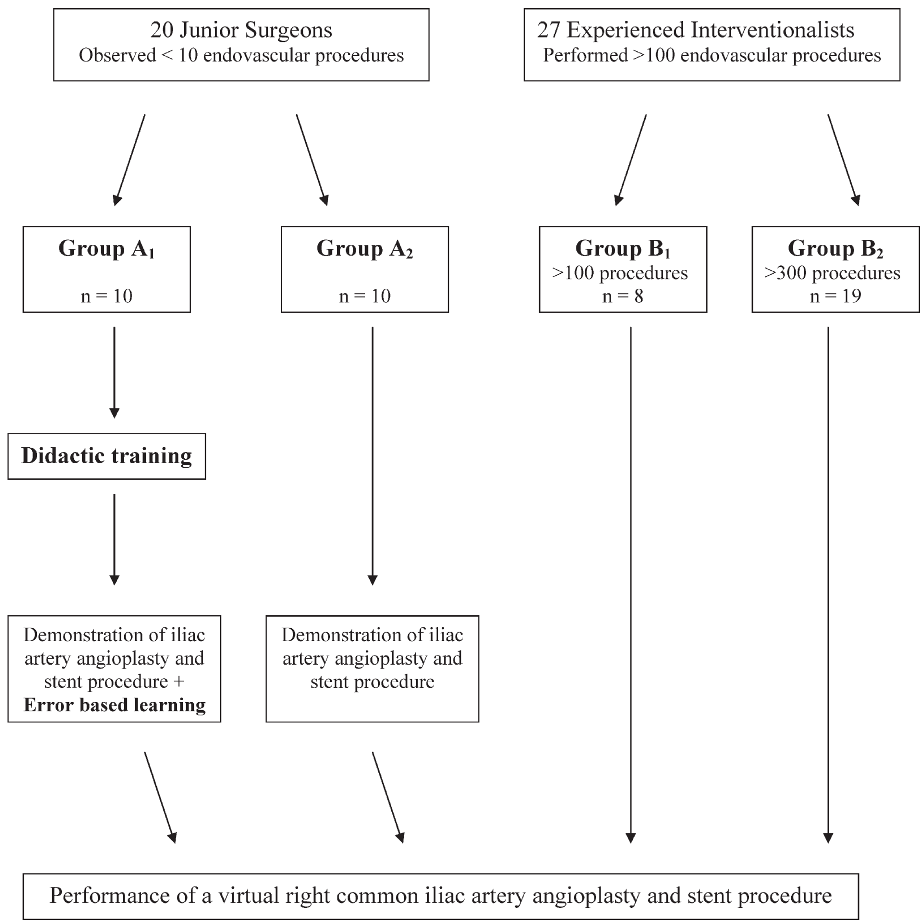

Fig 1. Study protocol.

not normally distributed), non-parametric tests were used. Comparisons of performance for continuous variables across the three groups were undertaken using the Kruskall Wallis test, between two groups using the Mann-Whitney *U* test. A level of $P < .05$ was considered to be statistically significant.

RESULTS

The demographics of the four groups are shown in Table II. None of the surgical trainees had performed, though the majority had observed, endovascular procedures. Only one participant in each group of student doctors had used an endovascular simulator, others had mostly used laparoscopic simulators. In the experienced group, seven interventionalists had experience with endovascular simulators for teaching.

The performances of the novices in both groups were compared to performances of the intermediate (>100 <300 procedures) and highly experienced (>300 procedures) subjects.

The cognitive-skills group who benefited from additional didactic training used a more appropriate stent size comparable to the more experienced interventionalists (median stent/vessel ratio A_1 0.89 vs B 0.96, $P = .960$). On the contrary, novices who did not receive didactic training prior to the simulated iliac artery procedure (group A_2) used a stent that was too small in relation to the vessel diameter compared to the experienced endovascular physicians (median stent/vessel ratio A_2 0.655 vs B 0.96, $P = .001$) (Fig 2). This resulted in a significantly greater residual stenosis in group A_2 (median A_2 35 vs B 4%, $P < .001$) when compared with the endovascular physicians whereas group A_1 were more successful with only a median residual stenosis of 11% (A_1 11 vs B 4%, $P = .511$) (Fig 3). No statistical significant differences were noted between the novices with or without didactic training and the experienced interventionalists for placement accuracy of the stent (%) or for percentage lesion coverage with the balloon or stent ($P > .050$).

Although the end-product assessment of group A_1 was significantly better, these novices were significantly slower (median total procedure time of A_1 982 seconds vs B 441 seconds, $P < .001$) while those without cognitive-skills training performed the procedure as quickly as the more experienced subjects (A_2 358 vs B 441 seconds,

Table II. Group demographics

	Group A_1 novices	*Group A_2 novices*	*Group B_1 intermediate*	*Group B_2 highly exp.*
Number of subjects	10	10	8	19
Number of performed endovascular procedures	0	0	>100 <300	>300
Gender: Male/female	6/4	9/1	7/1	18/1
Grade				
Junior resident	9	7	0	0
Senior resident	1	3	4	1
Consultant	0	0	4	18
Specialty				
Cardiology	NA	NA	2	4
Radiology	NA	NA	5	9
Vascular surgery	NA	NA	1	6
Main interest				
Vascular surgery	4	3	NA	NA
General surgery	4	4	NA	NA
Orthopedics	1	2	NA	NA
ENT	1	0	NA	NA
Emergency medicine	0	1	NA	NA
Simulator experience	5/10	4/10	0/8	7/19
Endovascular	1	1*	0	7
Laparoscopy	4	4	0	0

NA, Not applicable.
*One participant had used both an endovascular and laparoscopic simulator.

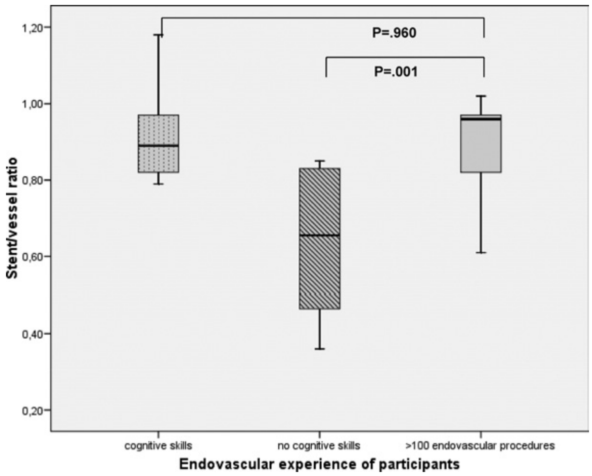

Fig 2. Box plot representing stent/vessel ratio during the virtual iliac procedure comparing the performance of novices (with and without cognitive-skills training) vs the experienced interventionalists (Mann Whitney *U*). The thick horizontal lines represent the medians, the boxes the interquartile ranges, and the whiskers the 5th and 95th percentiles.

P = .344) (Fig 4). Furthermore, the cognitive-skills group used fluoroscopy more liberally (median A_1 609 vs B 189 seconds, $P < .001$) while group A_2 pressed the fluoroscopy pedal for a shorter duration than the interventionalists (A_2 120 vs B 189 seconds, $P = .002$) (Fig 5). All groups used a similar amount of contrast to carry out angiograms during the intervention except for group A_1 though this value did not reach statistical significance (A_1 15 vs B 11 mL, $P = .602$; group A_2 10 vs B 11 mL, $P = .686$).

In addition, this study has shown that the performance of the intermediate (B_1) and highly experienced interventionalists (B_2) during the virtual iliac interventions was similar based on the metrics recorded by the simulator ($P >$ .050) (Table III).

DISCUSSION

This non-randomized prospective study has demonstrated that the quality of performance of the surgical trainees during a standardized non-complex iliac intervention was influenced by initial cognitive-skills training. The end product of the surgical trainees who benefited from cognitive-skills training was similar to that of interventionalists, despite inferior values on the quantitative assessment parameters, ie, they did better, though took longer to do so. On the contrary, the surgical trainees who did not benefit from one-to-one didactic cognitive sessions performed the intervention as quickly as the experienced interventionalists and pressed the fluoroscopy pedal for a shorter duration. However, their end-product assessment was significantly worse than the experienced physicians. The authors felt that additional fluoroscopy time in the didactic novice group (A_1) was used to exchange the different endovascular tools (eg, to ensure that the position of the guidewire or other tool was maintained) and to localize the position during inflation of the balloon or deployment of the stent. Certainly in order to achieve an accurate result in endovascular procedures, a minimum amount of fluoroscopy time is necessary, besides it is paramount in order to recognize errors and possible complications that may harm the patients.

The authors believe that the improvement in the completeness of angioplasty and stent placement was as a result of the additional cognitive training received but acknowl-

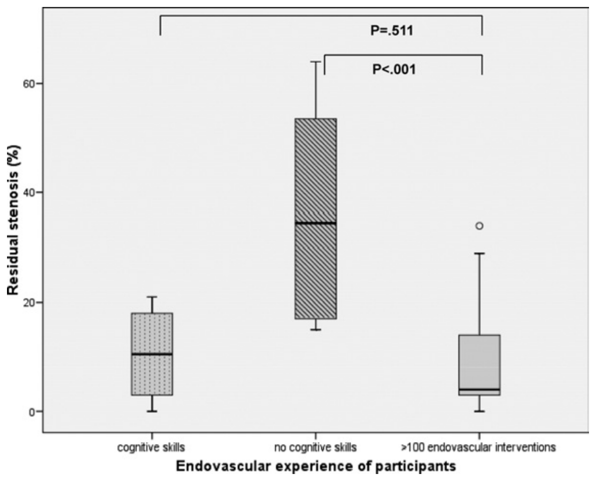

Fig 3. Box plot representing residual stenosis in a virtual iliac procedure comparing the performance of novices (with and without cognitive-skills training) vs the experienced interventionalists (Mann Whitney *U*). The thick horizontal lines represent the medians, the boxes the interquartile ranges, and the whiskers the 5th and 95th percentiles. The circles represent the outliers.

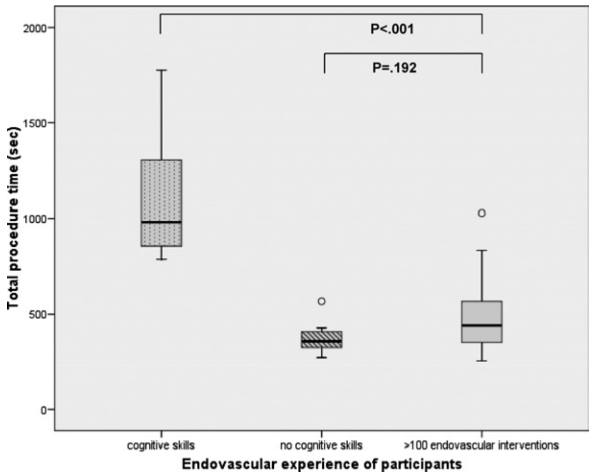

Fig 4. Box plot representing total procedure time used during the virtual iliac procedure comparing the performance of novices (with and without cognitive-skills training) vs the experienced interventionalists (Mann Whitney *U*). The thick horizontal lines represent the medians, the boxes the interquartile ranges, and the whiskers the 5th and 95th percentiles. The circles represent the outliers.

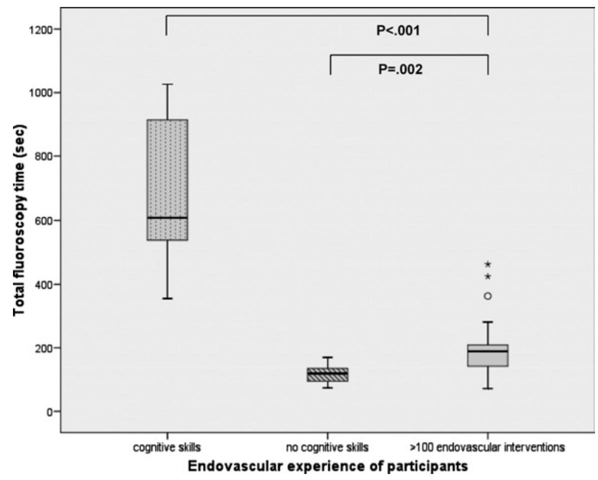

Fig 5. Box plot representing fluoroscopy time used during the virtual iliac procedure comparing the performance of novices (with and without cognitive-skills training) vs the experienced interventionalists (Mann Whitney *U*). The thick horizontal lines represent the medians, the boxes the interquartile ranges, and the whiskers the 5th and 95th percentiles. The circles represent the outliers and the asterisks the extreme cases.

edge that this improvement may have been as a result of a general increase in attention and enthusiasm during the didactic session. As stated by Satava[9] training in surgical skills has traditionally been through the apprentice model in which the student is taught what to do correctly. Seldom will the teacher explain to the students what an error is and what the consequences are both for the patient and the team. Simulators allow us to teach errors without putting a patient at risk and may improve the understanding of the trainees why, how, and in what order an intervention needs to be performed.

This study stresses the importance of cognitive-skills training prior to psychomotor skills training. As stated by Darzi et al performing a procedure faster only provides a crude assessment of the technical performance. A fast surgeon is not necessarily a good surgeon.[3,23] Surgical trainees or established vascular surgeons learning new techniques need to know how to use the knowledge attempting to perform a procedure.[5] To achieve optimal effectiveness, a technical skill should be taught in a detailed, step-by-step, standardized, analytical fashion.[24] As a surgeon develops expertise, the knowledge and procedural steps of a task become automated, experts often leave out important components when trying to describe a procedure.[25] In order to improve our understanding of the learning process, cognitive task analysis is mandatory to capture the automated elements of experts in a certain procedure and to improve the teaching and the assessment of technical skills.[26] Furthermore, error-based learning should be included since surgical skill has been shown to be associated with the ability to detect errors.[27]

Although this study did not carry out a strict task analysis, it has added weight to the argument that cognitive-skills training (teaching anatomy, the steps of a procedure, potential errors and complications, and handling of surgical tools) affects the performance of novice trainees during technical skills acquisition, albeit on a simulated endovascular procedure. Past validation studies that have sought to prove the construct validity of the endovascular simulators included a wide range of cognitive-skills training prior to assessment on the simulator. These varied from lectures, multimedia presentations, video, or live demonstrations of the virtual interventional

Table III. Construct validity of the VIST metrics across the three groups (cognitive skills group A_1 vs intermediate vs highly experienced endovascular physicians and non-cognitive skills group A_2 vs intermediate vs highly experienced endovascular physicians) using the Kruskall Wallis test

Assessment parameters	*Student doctors* A_1: *n* = 10 A_2: *n* = 10	*Group B1* >100 >300 *procedures* *n* = 8	*Group B2* >300 *procedures* *n* = 19	P *value*
Total procedure time (s)				
Median	A_1: 982 A_2: 358	401	441	A_1: **<.001** A_2: .192
Fluoroscopy time (s)				
Median	A_1: 609 A_2: 120	205	180	A_1: **<.001** A_2: **.002**
Stent/vessel ratio				
Median	A_1: 0.89 A_2: 0.66	0.96	0.94	A_1: .936 A_2: **.001**
Residual stenosis (%)				
Median	A_1: 11 A_2: 35	4	4	A_1: .770 A_2: **<.001**
Placement Accuracy (mm)				
Median	A_1: 2.0 A_2: 2.1	0.6	1.8	A_1: .472 A_2: .363
Lesion coverage by stent (%)				
Median	A_1: 100 A_2: 100	100	100	A_1: .319 A_2: .773

procedure.[2,3,14-16,28-30] In this study, the cognitive skills were taught by a teacher as investigating the ideal format for cognitive-skills training was not the subject of this paper.

Future validation studies of medical simulators should integrate structured and detailed cognitive-skills training prior to psychomotor skills assessment of novice subjects. Perhaps the next generation of simulators can incorporate modules to train cognitive-skills which might relieve the faculty of the responsibility of being present to teach these skills. It is vital to include feedback during training sessions as well, otherwise these new educational models will fail to augment the traditional teaching methods.[31]

Others have proven that the VIST simulator is a valid tool for training endovascular skills necessary to treat iliac lesions, especially in novices.[17,18] Construct validity of this iliac module has been demonstrated and its effectiveness of training has been shown. If endovascular novices are taught how to perform an endovascular procedure correctly including error detection, forward planning, and decision-making, then simple parameters such as total procedure time and fluoroscopy time are able to differentiate them from experienced endovascular physicians in a virtual non-complex iliac endovascular procedure. On the contrary, qualitative assessment parameters currently recorded by the iliac module of the simulator are unable to differentiate the surgical trainees who got cognitive-skills training from experienced physicians (Table III). Several explanations are possible such as the poorly-designed measuring tool, the lack of pressure gradients across the lesion, and the suboptimal tactile feedback when encountering the lesion.[18,32] It might also suggest that the qualitative metrics that are currently recorded are not well defined. Furthermore, physiological responses, errors, or complications which can result in patient injuries are currently not accounted for during iliac interventions on this type of simulator. A more comprehensive metric system needs to be included in future simulators to allow more accurate assessments of trainees.

In contrast to more challenging procedures like renal and carotid artery interventions[2,14,15,30] no differences in performance during virtual iliac interventions were noted between the intermediate (>100 interventions) and highly experienced group (>300 interventions) based on the assessment parameters of the VR simulator (Table III). These findings suggest that an uncomplicated ipsilateral common iliac artery angioplasty and stenting procedure is relatively easy to master; consequently intermediate interventionalists are as accomplished in performing the task as highly experienced interventionalists.

Potential limitations introduced into this study include that the two groups of novices were not entirely comparable since the demographics of the groups reveal differences in male/female ratios as well as in grades. The fact that three senior residents without any endovascular experience were included in the control group was not due to a lack of interest but due to a lack of opportunities to learn endovascular skills since chances to perform diagnostic interventional procedures are diminishing due to improved noninvasive imaging. Furthermore the virtual performance of the participants was not videotaped and reviewed by experts to evaluate their psychomotor skills using global and procedure-specific rating scales. This may have offered additional insight into the quality of performance across the four groups, particularly since the simulator used in this study did not record physiological responses or did not register the erroneous maneuvers which could cause injury to simulated patients. An additional confounding factor might be that none of the participants in the study were familiarized with the simulator by hands-on practice. It has though been suggested that even the experienced endovascular practitioners require one session to familiarize with the simulator.[2] Another limitation was that only one iliac module was tested, and that more complex virtual iliac lesions may demonstrate that there is a difference in quality of performance between novices and experienced physicians and even between moderately and highly experienced interventionalists. Furthermore, the influence of cognitive-skills training might have been more impressive if a more complex intervention, eg, carotid artery stenting had been utilized to assess the performance, however, as stated earlier, novices should first acquire generic basic endovascular skills prior to carrying out challenging and high-risk endovascular procedures.

Since the 1900s, technical skills have been taught using the apprentice model of training.[20] This teaching method is associated with great variability among teachers, inconsistent effectiveness, and potential risks for the patients used as subjects for training. Ultimately our ambition is to develop a validated stepwise proficiency-based training curriculum for acquisition of endovascular technical and non-technical skills. The curriculum should include cognitive-skills training followed by simulator-based training to help translate cognition into motor behavior in the presence of mentors. Additional simulator-based training should be continued in a stepwise approach until a pre-defined set of proficiency criterion (benchmark level) is reached for each step. Subsequently, further training will be continued and enhanced in the real world until the trainee reaches the appropriate level of skill, which should be assessed objectively prior to independent practice.

CONCLUSION

VR simulation provides a promising opportunity for assessment of endovascular skills prior to real life experiences, though cognitive-skills training of novices must commence prior to psychomotor-skills acquisition. To avoid the isolation of acquisition of technical endovascular skills from cognitive and clinical skills, simulation needs to be integrated into an appropriate curriculum. Simulation-based training is unlikely to replace real life experience although it may be an adjunct to teach basic and advanced endovascular skills with the hope of shortening and flattening the learning curve on our patients.

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AUTHOR CONTRIBUTIONS

Conception and design: IV, RA
Analysis and interpretation: IV, RA, FV, NC
Data collection: IV, SN, FV
Writing the article: IV
Critical revision of the article: IV, RA, SN, FV, AD, NC
Final approval of the article: IV, RA, SN, FV, AD, NC
Statistical analysis: IV, RA, NC
Obtained funding: AD, NC
Overall responsibility: IV, NC

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Table I, online only. Example of a standard ipsilateral common iliac artery stent procedure

- Insert a 0.035 wire into the iliac artery and move it into the infrarenal aorta crossing the lesion carefully
- Introduce a diagnostic catheter into the aorta over the 0.035 guidewire
- Remove the guidewire, change the orientation, if necessary, and obtain an angiogram
- Road mapping is available for use
- Choose the appropriate balloon
- Inflate the balloon and remove the balloon
- Obtain an angiogram using the diagnostic catheter
- Choose the appropriate stent
- Deploy the stent and remove the device
- Obtain an angiogram, using the diagnostic catheter
- If necessary, insert an appropriate post-dilation balloon, post dilate and remove the balloon
- Obtain a completion angiogram using the diagnostic catheter
- Remove all tools