The importance of expert feedback during endovascular simulator training

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Objectives: **Complex endovascular skills are difficult to obtain in the clinical environment. Virtual reality (VR) simulator training is a valuable addition to current training curricula, but is there a benefit in the absence of expert trainers?**
Methods: **Eighteen endovascular novices performed a renal artery angioplasty/stenting (RAS) on the Vascular Interventional Surgical Trainer simulator. They were randomized into three groups: Group A (n = 6, control), no performance feedback; Group B (n = 6, nonexpert feedback), feedback after every procedure from a nonexpert facilitator; and Group C (n = 6, expert feedback), feedback after every procedure from a consultant vascular surgeon. Each trainee completed RAS six times. Simulator-measured performance metrics included procedural and fluoroscopy time, contrast volume, accuracy of balloon placement, and handling errors. Clinical errors were also measured by blinded video assessment. Data were analyzed using SPSS version 15.**
Results: **A clear learning curve was observed across the six trials. There were no significant differences between the three groups for the general performance metrics, but Group C made fewer errors than Groups A ($P = .009$) or B ($P = .004$). Video-based error assessment showed that Groups B and C performed better than Group A ($P = .002$ and $P = .000$, respectively).**
Conclusion: **VR simulator training for novices can significantly improve general performance in the absence of expert trainers. Procedure-specific qualitative metrics are improved with expert feedback, but nonexpert facilitators can also enhance the quality of training and may represent a valuable alternative to expert clinical faculty. (J Vasc Surg 2011;54: 240-8.)**

Endovascular techniques are increasingly used in the surgical treatment of vascular disease,[1-3] with well-recognized advantages over open procedures.[4-7] However, the use of these techniques presents a number of training challenges, as the skill set required to perform these procedures differs from the skills required to perform open vascular surgery. It has been shown that there is a learning curve associated with these procedures, such as carotid artery stenting where a clear correlation has been demonstrated between case numbers and complication rate.[8-10]

Current vascular surgery training does not adequately prepare surgeons to perform these complex procedures. Pressures on training time, given current and future work hour restrictions[11,12] and the ethical[13] and practical issues associated with practicing complex skills in the clinical environment, make it difficult for vascular trainees to gain adequate experience. In addition, interventionalists from fields such as radiology, cardiology, and neurosurgery are now performing these procedures, further decreasing the clinical exposure available to vascular trainees.[14]

A solution to many of these training issues is the supplementation of clinical training with virtual reality (VR)-based simulator training. Already well established in other specialities, simulator training is particularly well suited to endovascular skills training, as it can easily mimic the real-life situation of manipulating a wire or catheter in a real, 3D field, while viewing this activity on a 2D monitor. High-fidelity simulators such as the Vascular Interventional Surgical Trainer (VIST) allow trainees to learn basic wire and catheter handling skills in a safe and economical environment and afford expert practitioners the opportunity to refine and refresh procedural skills. The educational value of high-fidelity simulators is well-established, and research has demonstrated construct validity of VIST simulator metrics[15-17] and a learning curve with repeated practice on a

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simulator,[17-19] and initial studies suggest skills gained on the simulator transfer to the clinical setting in both animal[20] and human models.[21] VR simulation training was mandated by the Food and Drug Administration in the United States for carotid artery stenting training in 2005.[22]

The question therefore is not whether simulation can be a useful adjunct to endovascular training, but how best to optimize its use. One important aspect of training is the use of feedback, already established as an important part of the learning process in both surgical training and the psychology literature. Mahmoud et al demonstrated that there was no learning curve on a colonoscopy simulator in the absence of feedback.[23] A range of other studies of surgical training have shown improvement in outcome parameters and more efficient learning when feedback is provided, although there is no consensus regarding the optimal style of feedback.[24-26] For example, one study suggested that simple knowledge of results may be as effective as expert instruction.[27] As there is a high cost and logistical difficulty associated with providing expert faculty for surgical training courses, it would be advantageous to know if this is necessary for optimal learning to take place. We propose to investigate this by comparing the effect of expert feedback, nonexpert feedback, and no feedback on trainee learning curves for a simulated endovascular procedure.

METHODS

Ethical approval was obtained from the Research and Ethics Committee Royal College of Surgeons Ireland prior to commencement of the study.

The simulator used in this study is the Procedicus VIST (Vascular Interventional Surgical Trainer) system [Mentice, Gothenburg, Sweden]).[28]

Participants

Subjects. The subjects were volunteer surgical trainees who were novice in endovascular procedures.

Inclusion criteria. Completed Basic Surgical Training (BST). This is a postinternship 2-year surgical training program.

Exclusion criteria. Commenced Higher Surgical Training. (This is a 6-year training program for specialist registrars, which usually commences 2 to 4 years after completion of BST.) Previously, performed any complete or partial endovascular procedures. Prior experience on VIST simulator, or any other high-fidelity vascular simulator (observation or assisting at an endovascular procedure was not considered an exclusion criterion).

Facilitators. Expert and nonexpert facilitators were involved in the study. All facilitators underwent a standardized training program for the VIST simulator and were familiar with the simulated procedures and metrics.

Expert facilitators. Consultant vascular surgeons who perform endovascular procedures and are currently working in Ireland.

Nonexpert facilitator. Surgical trainee with no clinical vascular or endovascular experience.

Study procedures

Eighteen trainees were recruited. Demographic data were collected, including information regarding prior laparoscopic surgical experience, and video-game use.[28]

Visuospatial testing. All subjects underwent a standard battery of perceptual, psychomotor, and visuospatial tests. This was to ensure that no significant baseline differences existed between the groups.

Didactic teaching. The procedure selected for the study was a left renal artery angioplasty and stenting (RAS). The exact steps for performing this were taught in a standardized fashion to every subject.

The teaching session comprised the following elements:

- A power point lecture covering the background to and steps of the procedure
- Demonstration of the procedure on the VIST simulator with commentary and advice regarding common errors
- Postdidactic questionnaire. Subjects were told the correct answers after completion if they did not score 100%.

Simulated procedures

All subjects then proceeded to perform six RAS procedures each. They could not perform more than two procedures without taking a break.

As ability to memorize correctly the steps of the procedure was not specifically being tested, all candidates had access to a set of written instructions outlining the basic steps of the procedure.

Although the procedure was not performed with a sterile field, it was kept clinically realistic in other ways. For example, when changing instruments, subjects had to remove the instrument fully from the guidewire even when the actual instrument being used for the subsequent step was the same physical instrument. All subjects were offered assistance with changing of instruments. In addition, the facilitator recorded cineloops and roadmaps where requested and performed C-arm positioning and instrument selection on the simulator as instructed by the subject.

Candidates were not given any coaching or direction during the procedure unless there was a risk of damaging the simulator. If they had questions, they were directed to read the written instructions. However, if they were still unsure of what to do next, they were given appropriate instructions, as the aim was not to test cognitive memory of the procedural steps.

Due to time and scheduling restrictions, the decision was made to limit the time allowed for any one procedure to 40 minutes. This did not affect most subjects, but on several instances, some subjects who were performing their first or second procedure could not complete it within the allowed time. No subject performing their third or greater procedure was limited by time.

Table I. Vascular Interventional Surgical Trainer (VIST) error metrics

Catheter scraping against vessel wall
Catheter moving without support of wire
Selective catheter scraping against vessel wall
Selective catheter moving without support of wire
Guidewire in small vessel
Guidewire entered suboptimal vessel
Catheter entered suboptimal vessel

Groups

Subjects were randomized into three groups (using a block randomization scheme with blocks of nine).

Group A – control. Subjects in this group performed their procedures with assistance/facilitation as described above. Although they were aware of the duration of their procedure, they were given no other feedback regarding their performance.

Group B – nonexpert feedback. The subjects in this group performed their procedures in an identical environment to those in Group A, except that they were given feedback after every procedure.

Three performance areas were discussed:

- Procedural time, fluoro use, and contrast use
- Accuracy of balloon/stent placement
- Handling errors as assessed by the simulator.

In addition, they were given feedback relating to the advice that had been supplied before the procedure and also feedback regarding any additional errors made, such as incorrect instrument selection or use.

Group C – expert feedback. These subjects were given feedback after every procedure by an expert, who also observed their performance. Experts were instructed to give whatever feedback they considered appropriate. In practice, all the experts went through the simulator metrics with the subject and then gave additional feedback.

Performance assessment

The performance assessment included two main elements—simulator-generated metrics and video-based performance assessment.

Simulator metrics. The VIST simulator objectively records performance parameters for every procedure performed. These parameters can be divided into three categories:

General. This provides results for fluoroscopic and total procedure time and volume of contrast use.

Per lesion report. This includes measurements for the appropriateness of the size of balloon/stent and the accuracy of the balloon placement (distance in mm between the center of the lesion and the center of the balloon/stent) and stent deployment.

Handling errors. Errors made during the procedure (Table I).

Video-based assessment. Every procedure was videotaped. The procedural screen only of the simulator was recorded by the camera. In each case, the trainee's face was not recorded, so that the videos could be assessed in a blinded fashion. The recordings were made in order to provide a separate source of assessment, as the VIST error metrics have been criticized for showing poor construct validity in some studies. Some of the VIST errors were deemed unfair by the experts; for example, catheter scraping against wall of the vessel, as it is difficult to avoid this error when cannulating the renal artery.

A standardized assessment form was created for the video assessments (Appendix, online only). This consisted of a detailed error-scoring sheet. Errors were scored every time they occurred and all were weighted equally and given a score of 1. All videos were assessed by one of the authors (EB).

Statistical analysis. Data were analyzed using the Statistical Package for the Social Sciences version 15.0 (SPSS, Chicago, Ill). Data from the subjects' performance were analyzed using non-parametrical tests. Differences between the groups' mean scores were compared for significance with Kruskal-Wallis testing, and pairs of Mann-Whitney *U* tests were used to identify specific statistically significant differences between the groups. Improvements between the groups were compared using repeated measures analysis of variance where within-subject comparisons were the trial number and between-subject comparisons were the group to which the subject belonged.

RESULTS

Eighteen subjects in total participated. All subjects completed all six trials, but for one subject, the simulator malfunctioned for two of the procedures, so only four attempts were recorded. For the purposes of analysis, this subject's results for trial four were repeated for trials five and six, which was a conservative approach, as there had been a continuous improvement throughout the previous four trials and it would be reasonable to presume that this trend would have continued.

Twelve of the 18 subjects completed all six trials within 1 day. For six of the subjects, this was not possible due to scheduling restrictions, and in these cases, all trials were completed within a 3-day period.

Demographics. Demographic data are presented in Table II. No significant differences existed between any of the groups for age, years since graduation, wearing of glasses, handedness, or visuospatial abilities when compared using Kruskal-Wallis tests.

Overall results for simulator and video metrics. When all 18 subjects' results were analyzed together, the most striking finding was the presence of a clear learning curve. All subjects improved their performance from their first attempt to their last. When analyzed using non-parametric analysis of variance for repeated measures (Friedman), there was a significant learning curve for all simulator metrics and for the video error scores (Table III).

The learning curve was perhaps most notable for procedural time, as on trial one and two many subjects were unable to complete the procedure within the time limit. By

Table II. Demographic data

Demographic	*Figures*			*Significance of between group difference* (P)
Mean age/years	30.27 (3.54)			NS
Mean years since graduation	5 (1.15)			NS
Wear glasses	Yes, 10	No, 8		NS
Video games	Yes, 4	No, 14		NS
Endovascular procedures	None, 11 Assisted, 7 Performed, 0			NS
Visuospatial test scores/group	A	B	C	
Paper tests[a] (overall mean %)	59%	43%	54%	NS
PicSOr[b] (mean)	0.93	0.87	0.86	NS
ProMIS - [c]time/sec	381	406	398	NS
ProMIS -IPL/mm	7649	5517	5575	NS
ProMIS - IS/count	1219	944	1117	NS

[a] Ekstrom R, French J, Harman H. Manual for kit of factor-referenced cognitive tests. Princeton, NJ: Educational Testing Service; 1976.

[b] Gallagher AG, Cowie R, Crothers I, Jordan-Black JA, Satava RM. PicSOr: an objective test of perceptual skill that predicts laparoscopic technical skill in 3 initial studies of laparoscopic performance. Surg Endosc 2003;7:1468-71.

[c] 'Instrument handling-locating and co-ordinating' task on the ProMIS laparoscopic surgical simulator (Haptica, Dublin).

Table III. Significance of learning curve using non-parametric analysis of variance

Metric	*Significance (Friedman)*
Time	.000
Contrast	.000
Fluoro	.000
Errors	.000
Placement accuracy	.047
Residual stenosis	.001
Lesion coverage	.000
Video errors	.000

trial three, all subjects were able to complete the procedure, and by the fifth or sixth trial, all subjects were completing the case in less time (Fig 1, *a* and *b*).

There was also no significant difference between the performance of the three subjects who played video games for at least 1 hour a week compared with those who did not.

Between-group differences for simulator scores – effect of feedback. Results for procedural time, contrast use, fluoroscopic time, error scores, and accuracy of balloon placement scores were summed over the six trials for each subject. For each metric except placement accuracy, Group C performed better than Groups A and B, and for each metric except fluoroscopic time and residual stenosis, Group B performed better than Group A. However, when these results were compared using Kruskal-Wallis, significant differences existed between the groups for error scores only. Post hoc testing using pairs of Mann-Whitney *U* tests revealed that the significant results were between Groups A and C ($P = .009$) and Groups B and C only ($P = .004$; Table IV).

To further assess the effect of feedback, we compared the group's mean scores on their sixth and final attempt at the procedure (Table V).

As can be seen from the results, Group C out-performed the other two groups in every metric, significantly so for placement accuracy and error scores, and the difference for contrast approached statistical significance, and, on a practical level, the differences for this metric were marked (24.9 mL vs 17.2 mL vs 9.55 mL; Table V). Post hoc testing showed that for the errors scores, significant differences again were between Groups A and C and Groups B and C ($P = .004$ and $P = .009$, respectively) and for placement accuracy only between Groups A and C ($P = .041$).

When individual learning curves for the three different groups were analyzed, there were no statistically significant differences in the individual learning curves when assessed using repeated measures two-factor analysis of variance with the individual metrics such as time, contrast, fluoro use, and error scores as the second factor. However, Fig 2, *a-d* show that the subjects in Group C demonstrated a smoother learning curve and reached a plateau by trials four or three in all cases when compared with the other groups. On trial four, differences between the three groups were statistically significant for time and errors.

Between-group differences for video assessment scores. All videos were assessed in a blinded fashion. For the error scores, the total errors for each group were averaged and are presented in Fig 3. As can be seen from the figure, Group C performed better than Group B, who performed better than Group A. Significant differences were found between the groups ($P = .000$). Post hoc testing using Bonferroni showed that the significant differences were between Group A, and Groups B and C (Table VI).

DISCUSSION

The primary aim of this study was to assess the value of feedback in simulator-based training programs and to compare expert with nonexpert feedback. A significant and increasing body of research is supporting the use of simulation in surgical training, and there is ample published evidence that skills gained in the simulation laboratory transfer to the operating room,[29-32] and this has also been specifically demonstrated for endovascular simulators, both in animal[20] and human[21] models. There is also increasing evidence about the best way to use simulation. Simulator-based training should be incorporated into a complete curriculum,[33] with initial cognitive training,[34] a predefined proficiency level which trainees must reach,[35,36] and the chance to experience distributed practice sessions.[37,38] The use of feedback has also been studied, and although feedback has been shown to improve performance, the optimal type of feedback has not been established. The provision of feedback is a well-recognized tool in the aviation training

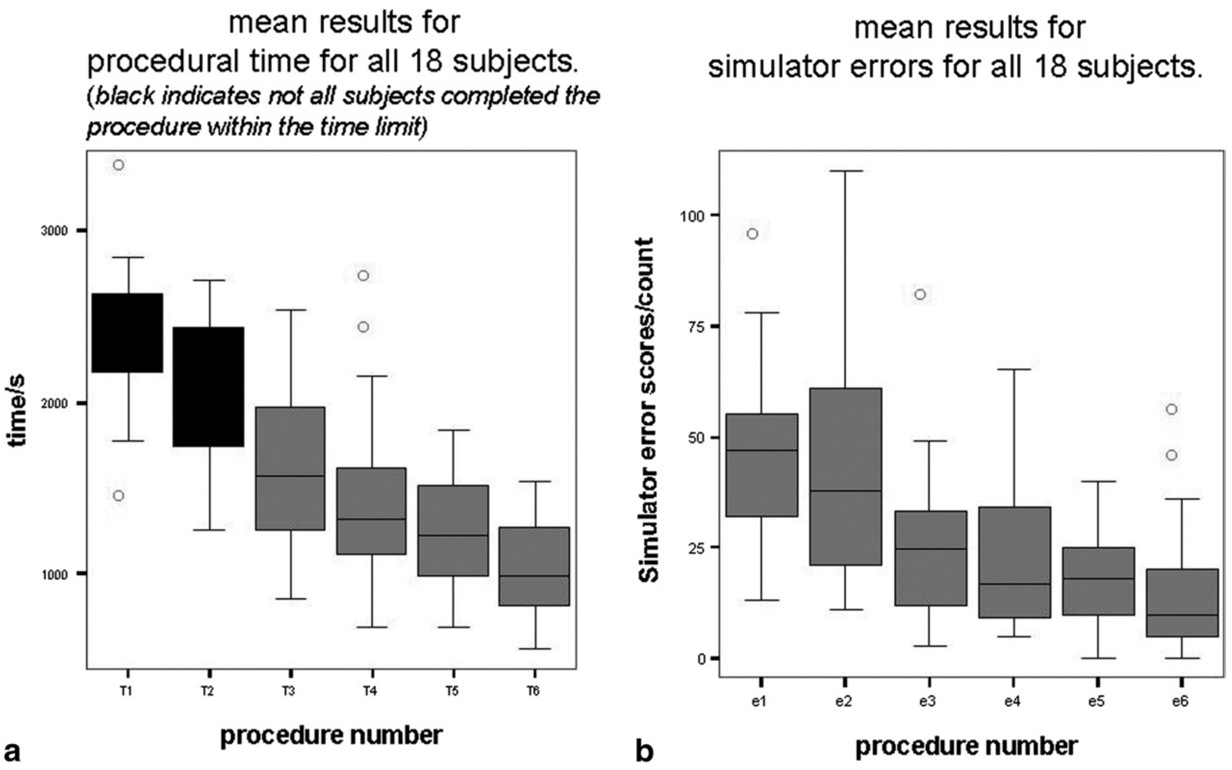

Fig 1. Results for time **(a)** and error **(b)** scores for all 18 subjects.

Table IV. Overall results for the three groups

Metric	*A*	*B*	*C*	P *value (Kruskal-Wallis)*
Time (s)	10,606	9809	8672	.104
Contrast volume (mL)	214	132	109	.148
Fluoroscopic time (s)	6212	6399	5255	.359
Error scores	217	204	101	.009[a]
Placement accuracy (mm)	31	19	22	.296
Residual stenosis	24	28	12	.333
Lesion coverage (%)	481	467	544	.584

[a]Statistically significant.

Table V. Differences between the groups for trial six

Metric	*A*	*B*	*C*	P *value (Kruskal-Wallis)*
Time (s)	1014	1064	900	.470
Contrast volume (mL)	24.9	17.2	9.55	.078
Fluoroscopic time (s)	6212	6400	5390	.459
Error scores	17	27	4.7	.016[a]
Placement accuracy (mm)	5.18	2.87	0.85	.019[a]
Residual stenosis	19.5	13.5	1.5	.791
Lesion coverage (%)	87.83	93.67	100	.183

[a]Statistically significant.

industry, where simulation training is much better established. Airline training encompasses human factor and crew resource management training in addition to technical skills, and posttask debriefing sessions are an important part of this, although more suited to group training sessions.[39] Debriefing gives powerful feedback, and other tools such as simulator cameras and data recording can also give individualized trainee feedback. Feedback is less well established in surgical training probably because the removal of parts of training from the clinical environment is a more recent development. It is not clear, for example, if the presence of a clinical expert would improve the trainee's technical performance more than the presence of a non-clinical facilitator or by how much the trainee's performance will improve when they are given feedback compared with no feedback.

All the subjects in the study improved their overall performance significantly as they performed the six procedures, but for the general procedural scores, there was no difference in the rate of improvement in the subjects who did and did not receive feedback. However, there were significantly fewer errors committed by the subjects who received expert feedback, both when compared with Group A, the control, and Group B, who had feedback from a nonexpert facilitator.

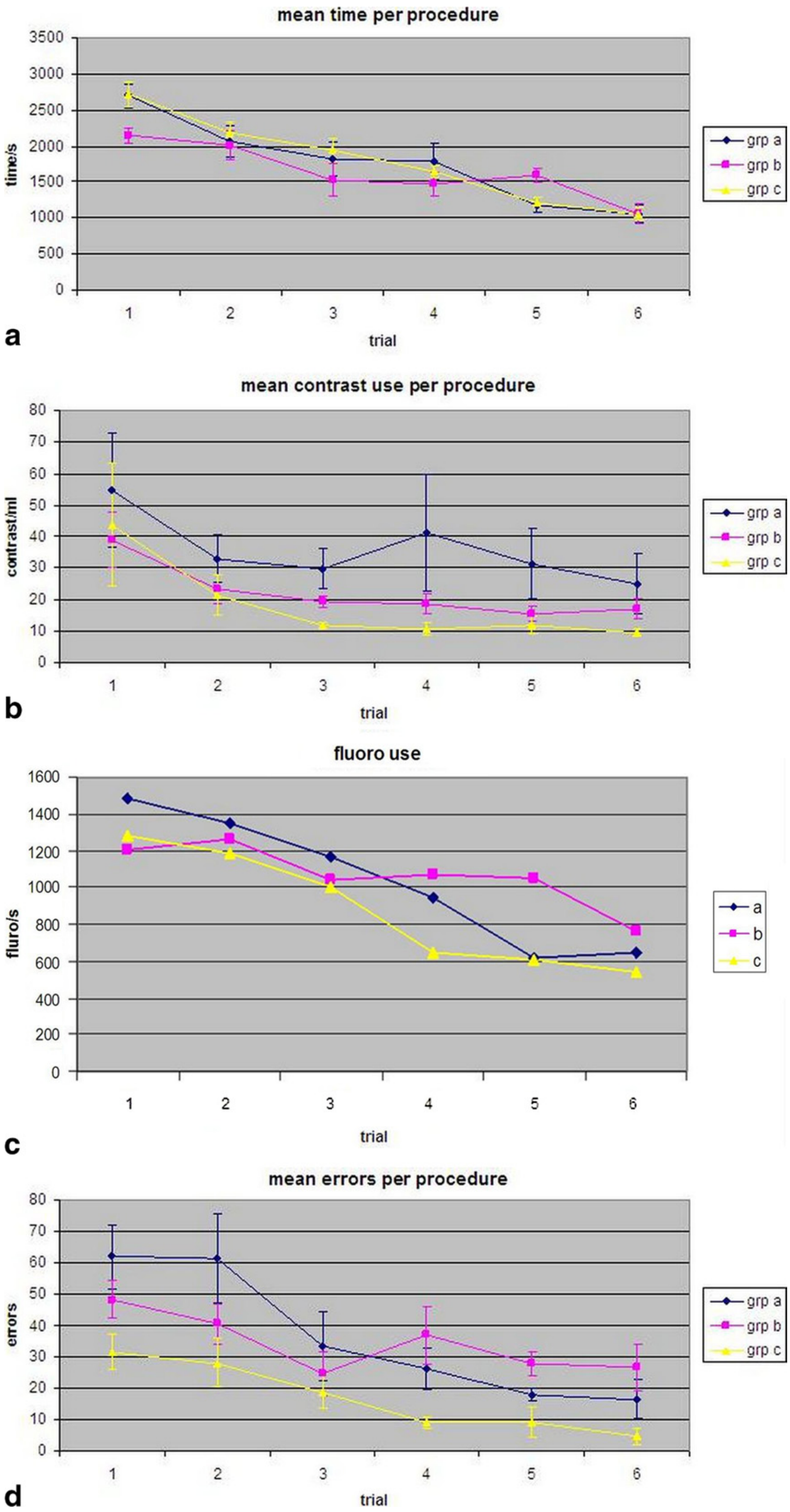

Fig 2. **a**, Individual learning curves for procedural time. **b**, Individual learning curves for contrast volume. **c**, Individual learning curves for fluoro time. **d**, Individual learning curves for error scores.

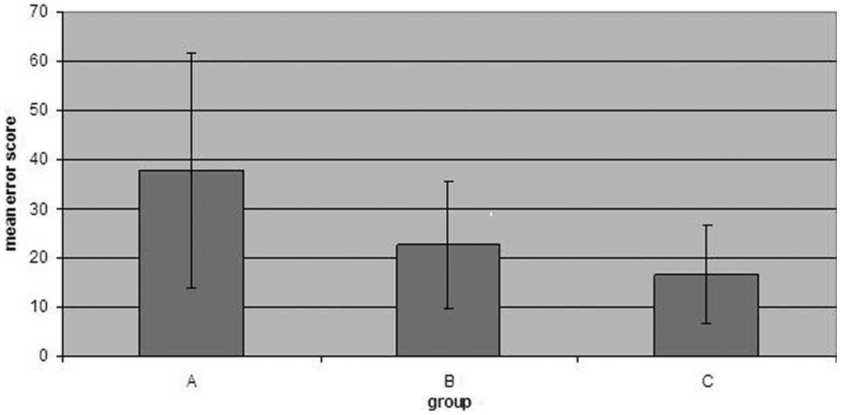

Fig 3. Mean error scores for all six trials for each group.

Table VI. Post hoc testing

Posthoc comparisons	P *value*
Groups A and B	.002
Groups A and C	.000
Groups B and C	.428

This demonstrates the extra benefit of expert feedback during simulator-based courses, but also shows that certain elements of the procedural skill set are less reliant on feedback. Hislop et al[40] had similar findings, in that they separated time to complete a procedure ("innate endovascular skill") from qualitative assessment of procedure, which was based on observer ratings of performance and found that previous experience and skill level correlated with better qualitative performance but not time to complete the procedure, suggesting the generic skills necessary to perform such procedures quickly are separate from ability to perform the procedure well. Although there is some benefit in mastering the instrument handling skills in the simulator environment before proceeding to the real procedure – the "pretrained" novice – [33] it is obviously optimal to also cultivate good, safe habits, as there is a risk that the simulator could reinforce bad practice in the absence of feedback.[41] It could raise the confidence levels of novices while allowing them to practice serious errors. In addition, there is a certain amount of intrinsic feedback with regard to the generic performance measures in that the trainee knows how long they spend performing the procedure and how many mLs of contrast they have used; therefore, there may be little extra benefit from feedback regarding these performance measures. It is true that the mere presence of an expert may also be a factor, as the subjects in Group C may have felt under more pressure to perform due to the presence of an expert. Certainly, some differences in performance were noted on trial one (Fig 2, *a* and *d*), and subjects in Group C tended to perform better although baseline characteristics of all the groups were similar. It was also clear during the data collection sessions that subjects in Group C were very conscious of the presence of the consultant. However, the subjects in the other groups were also motivated to perform well and try to outperform their peers.

In addition to a superior overall performance when results from all trials were combined (Table V), the learning curve data in Fig 2 clearly show a smoother learning curve for the Group C subjects. They tend to plateau earlier, by trial three or four in all cases. If expert tuition can help trainees to reach proficiency after less practices, this has implications in an era of work-hour restriction and training time pressure. In addition, the performance of the Group C subjects tended to be more consistent, which is an important safety issue in the real clinical environment where it is important that a surgeon performs well and consistently to a high standard.

All performances were recorded on DVD to provide an additional method to objectively assess performance. Some of the VIST metrics have been questioned regarding their validity and have not consistently been demonstrated to be construct valid. We assessed performance using a checklist for specific errors. This error assessment revealed significant differences between the three groups (Fig 3). However, on video analysis, performance error scores were not significantly different in Groups B and C, suggesting that for the more clinically relevant markers of a superior performance, nonclinical experts can give equally valuable feedback. In this analysis, different errors were not weighted, but it would be interesting if more clinically serious errors were weighted more heavily. As videos were recorded, these could also be a useful training resource for the trainee - they could watch taped performances on a separate occasion and score themselves, which would be a valuable learning resource.

The subjects were endovascular novices and all showed a significant learning curve over the course of the six procedure repetitions. The improvements seen during a relatively short period of training in a group of novices has been seen elsewhere in the literature.[17,19] As a time limit of 40 minutes was used for each procedure, the completion rate among the subjects for trial one was not 100% (Fig 1, *a*); in fact, 7 of the 18 subjects failed to complete the procedure on their first attempt. However, all subjects were able to complete the procedure by their third attempt. This shows the benefit of repeated, structured practice, something which is difficult to achieve in the clinical environment. A trainee might typically have the opportunity to perform a particular procedure once during a list, and there may be a long time interval before their next opportunity during which time their skills may have decayed. In addition, procedures vary hugely from case to case - simulator training gives the opportunity to practice an identical procedure several times, building confidence and skill.

While simulators can never replicate fully the clinical experience, they have the potential to be a valuable adjunct to clinical training and indeed enhance the benefit from clinical experience. The metrics are appropriate and aim to reinforce good and safe habits. We demonstrated significant correlations between several of the different metrics. Potentially, if trainees were instructed to access the performance report provided by the simulator after every performance, they could potentially derive some of the same benefit from performance feedback provided by an observer.

One of the important advantages to simulator-based training is its efficiency and cost effectiveness (although high-fidelity simulators are expensive, they can save valuable theater time, are a once-off investment, and will hopefully become cheaper as the market expands), and moving some elements of skills training from the operating environment to the skills laboratory solves some inherent problems with training in the clinical environment. As there is a high cost and logistical difficulty associated with providing expert faculty for surgical training courses, it is advantageous to know what effect this has on learning. Our results show that while learning may be optimal with feedback from an expert, training on the simulator in the absence of feedback can also be extremely beneficial.

CONCLUSION

In conclusion, we have demonstrated that short intensive training allows novices to make significant performance improvements. Generic skills are improved regardless of the availability or provider of feedback, meaning that even independent practice on a simulator is beneficial, but performance is more free from procedural errors when feedback is provided. For the objectively assessed simulator errors, feedback from an expert was associated with a significant performance improvement, but for the video-based assessment, nonexperts appeared to give equally valuable feedback. Therefore, while expert faculty are desirable at intense skills courses, such training has other benefits if faculty are not available. Objective assessment of performance correlated well with the simulator metrics, supporting their use. Viewing of procedural videos could be incorporated into training regimens. We feel these findings have relevance to the designing and development of endovascular training curricula.

AUTHOR CONTRIBUTIONS

Conception and design: EB, DO, PN, AH, CM, DM
Analysis and interpretation: EB, DO, PN, AH, CM, DM
Data collection: EB, CM, DM
Writing the article: EB
Critical revision of the article: EB, PN, DM
Final approval of the article: EB, DO, PN, AH, CM, DM
Statistical analysis: EB
Obtained funding: Not applicable
Overall responsibility: EB

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Appendix (online only). Scoring sheet using for assessing DVDs

Procedure code: ________________

	Steps	*Errors*	*#*	*sc*
1	Advance guidewire into aorta	Advance without following		
		Advance to wrong position >T12, <L3		
2	Introduce pigtail	Wrong instrument		
		Fail to visualize GW tip while inserting		
		Fail to stabilize GW		
		Advance too far (>T12), not enough (<L3)		
		Fail to pull back slightly on pigtail		
3	Obtain renal angiogram	Insufficient view of RA, need to repeat		
		Fail to repeat if insufficient		
4	Remove pigtail	GW curls/buckles in aorta		
		Move too fast		
		Fail to visualize		
5	Reinsert GW	Advance without following		
		Advance to wrong position >T12, <L3		
6	Insert diagnostic catheter to L1	Wrong instrument		
		Fail to visualize GW tip while inserting		
		Fail to stabilize GW		
		Advance too far (>T12), not enough (<L3)		
		Fail to pull back slightly on catheter		
7	Cannulate renal artery	Fail to rotate to left		
		Fail to maintain left position		
		Fail to withdraw slowly		
		Fail to recognize if tip engages with RA		
		Cannulate wrong vessel		
		Cannulate but pull catheter out		
		Need to repeat, (have to pass catheter prox to RA again)		
		Fail to obtain angiogram		
		Insufficient, ie stenosis not visualized		
		Fail to repeat if insufficient		
8	Insert guidewire into RA, exchange diagnostic catheter for guide catheter	Insert GW too far into RA		
		Fail to stabilize GW		
		Pull GW out of RA when removing catheter		
		Guide catheter angled to right		
		Pull GW out when inserting guide catheter		
		Need to repeat steps V-IX		
		G catheter not engaged with RA ostium		
		Insert guide catheter past lesion		
9	Insert balloon	Failure to use road map to guide size		
		Inappropriate size		
		Insert GW too far		
		Pull guide catheter out of RA		
		No use road map		
		Fail to center balloon over lesion		
10	Angioplasty	Inflate inside guide catheter		
		Move balloon, not look while inflating		
		Withdraw before deflating		
		Fail to stabilize GW		
		Fail to stabilize guide catheter		
11	Exchange balloon for stent	Pull out guide catheter		
		Insert guide catheter past lesion		
		No use road map		
		Fail to center stent over lesion		
		Insert GW too far into RA		
12	Deploy stent	Inflate inside guide catheter		
		Move stent while inflating		
		Withdraw before deflating		
13	Completion angiogram	Fail to keep GW in aorta		
		Fail to visualize GW while inserting catheter		
		Fail to stabilize GW		
		Advance too far (>T12), not enough (<L3)/not at stent		
		Insufficient view of RA, need to repeat		
		Fail to repeat if insufficient		
		RA not patent		
14	Removal of instruments	GW curls/buckles in aorta on removal		
		Fail to visualize		

GW, Guidewire; *RA*, renal artery.