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Validation of Virtual Reality Simulation for Percutaneous Renal Access Training

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Abstract

Objective: The objective of this study was to assess the face, content, construct, convergent, and predictive validities of virtual reality-based simulator in acquisition of skills for percutaneous renal access.
Materials and Methods: A cohort of 24 participants comprising novices ($n = 15$) and experts ($n = 9$) performed a specific task of percutaneous renal puncture using the same case scenario on PERC Mentor™. All objective parameters were stored and analyzed to establish construct validity. Face and content validities were assessed by having all experts fill a standardized questionnaire. All novices underwent further repetition of the same task six times. The first three were unsupervised (pretest) and the later three after the PERC Mentor training (posttest) to establish convergent validity. A subset of five novice cohorts performed percutaneous renal access in an anesthetized pig before and after the training on PERC Mentor to assess the predictive validity. Statistical analysis was done using Student's *t*-test ($p \leq 0.05$ statistically significant).
Results: The overall useful appraisal was 4 in a scale of 1 to 5 (1 is poor and 5 is excellent). Experts were significantly faster in total performance time 187 ± 26 versus 222 ± 29.6 seconds ($p < 0.005$) and required fewer attempts to access 2.00 ± 0.20 versus 2.8 ± 0.4 ($p < 0.001$), respectively. The posttest values for the trained novice group showed marked improvement with respect to pretest values in total performance time 42.7 ± 6.8 versus 222 ± 29.6 seconds ($p < 0.001$), fluoroscopy time 66.9 ± 10.20 versus 123.3 ± 19.40 seconds ($p < 0.0001$), decreasing number of perforation 0.8 ± 0.3 versus 1.3 ± 0.2 ($p < 0.001$), and number of attempts to access 1.3 ± 0.10 versus 2.00 ± 0.20 ($p < 0.001$), respectively. Access without complication was attained by all five when compared with one with three complications (baseline vs. posttraining group, respectively) in the porcine model.
Conclusion: All aspects of validity were demonstrated on virtual reality-based simulator for percutaneous renal access.

Key message: To our knowledge, this is the first report incorporating all validities in a single study of virtual reality (VR) percutaneous renal access. A high-fidelity VR simulation is achieved by PERC Mentor™. It offers a realistic simulation of percutaneous renal access encountered in clinical practice. VR-based training has the potential to become a standard tool for clinical education.

Introduction

Percutaneous renal access is the initial and the critical step in performing percutaneous nephrolithotomy (PCNL). Hands on intraoperative training on live subjects continue to be the primary method of learning percutaneous renal access. Because of ethical concerns, this type of training has been challenged with widely available skill laboratories offering training models. Proper validation studies are necessary to use models in an evidence-based manner.[1] Currently, three high-fidelity bench models and one virtual reality (VR) simulator have been detailed for their utility in learning percutaneous renal access.[2]

Although distribution of computer-based simulators is limited by high prices, VR-based training has the potential to become an important tool for clinical education.

We hypothesized that VR simulator facilitates the performance of basic endourologic tasks such as percutaneous renal

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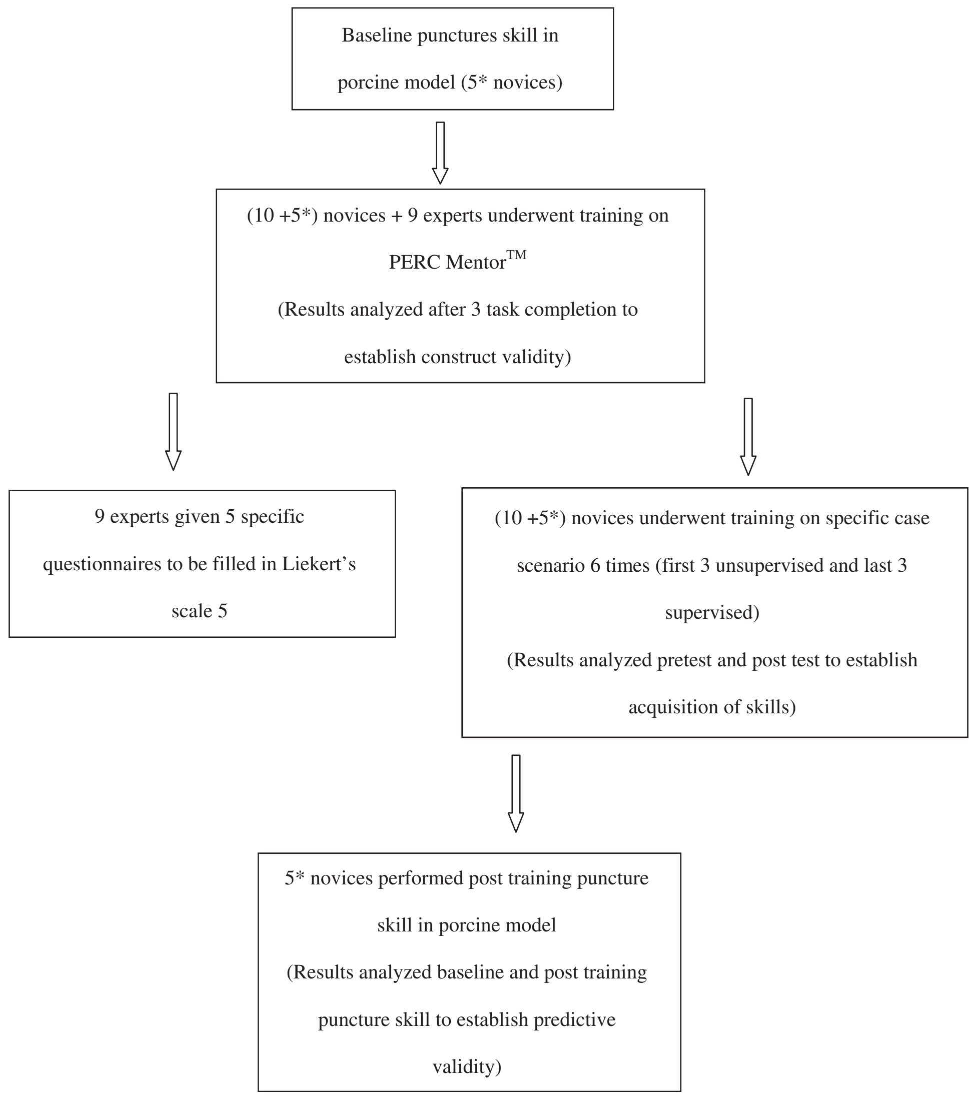

FIG. 1. Study flow chart. *These are the subset of 5 novices who performed the baseline puncture skill assessment on porcine model, completed the virtual reality training and then performed predictive validity skill assessment again on the porcine model.

access and translates to a better performance in the operating room. Our objective was to test the different validities of VR training for percutaneous renal access.

Materials and Methods

The place of the study was Jayramdas Patel Academic Centre, Nadiad, between April 2007 and April 2008. The armamentarium included PERC Mentor™ (Simbionix, Lo, Israel) in the dry laboratory and female porcine in the wet laboratory. A total of 56 participants performed the training in the wet and dry laboratories, and complete data evaluation of only 24 was available. They were divided into a cohort of 15 novices and 9 experts. The expert group had clinical experience of doing PCNL in more than 50 cases. The PERC Mentor is a VR simulator specifically developed for training in percutaneous renal access. It comprises of a personal computer system located under a workstation. The central software system includes a proprietary visualization engine, which allows real-time simulation by offering a high-level object-orientated application program interface (written in C++) available for use with either Microsoft® DirectX 7® or OpenGL platforms (Simbionix, Lo, Israel).

It incorporates tactile feedback, organ displacement with breathing, real-time fluoroscopy using virtual C arm, and mock angiographic instruments. A needle with metal sensor is used to achieve percutaneous access into a digitally projected renal collecting system. It can deliver contrast medium on demand via a retrograde ureteral catheter, and fluoroscopic imaging being controlled with a foot pedal. Real-time feedback confirming puncture is available by way of aspiration from the needle. The training consists of choosing different task scenarios of increasing complexity (www.simbionix.com/PERC_Mentor.html).

The porcine model study was approved by the Institutional Animal Ethics Committee. The study flow chart of the exercises is shown in Figure 1.

First exercise

Of the 15 novices, a subset of 5 novices performed training on the porcine model before the training on PERC Mentor.

Table 1. Results of Face and Content Validities (Experts)

Face validity questionnaire	Subjective field	Median score (range, 1–5)
1	Overall appraisal	4
2	Simulation of ease/complexity	3
3	Graphics	3
4	Training tool	5
5	Assessment tool	3

Only access to the pelvicaliceal system by means of needle puncture without passage of guidewire was defined as puncture. The novices received an orientation course in terms of the anatomy of the pelvicaliceal system after injecting contrast from the ureteral catheter and their intended direction of the access tract. However, no tissue feel or an introductory trial and error chance was allowed to fulfill their novice status. Assessment of baseline puncture skill was done by an single, independent expert observer (R.B.S.) noting the novice perform percutaneous renal access in an appropriately anesthetized pig. Prior to percutaneous access, pig underwent bilateral ureteral catheterization for opacification of the collecting system. Objective parameters including access, misdirected puncture, and complication were noted.

Second exercise

All the 24 participants (expert and novice groups) performed the second exercise on PERC Mentor after orientation to the simulator by way of an introductory session and a trial run. The participants attempted to perform a specific case scenario (percutaneous nephrostomy normal, no. 2) thrice on the PERC Mentor. All objective parameters including overall operative time, number of punctures, fluoroscopy time, incorrect puncture, complication, and amount of contrast material used were recorded by the software of the program and stored as a data metric after the procedure. The result was analyzed to establish the construct validity (recognition between expert and novice) and baseline objective parameter value (pretest) for the novice group. A standardized questionnaire (Liekert's scale 5) (Table 1) was given to the expert group to assess the face and content validities (whether experts consider the tool to be an accurate and reasonable representative of the task) of the simulation.

Third exercise

The novice group then received two 30 minutes of supervised training session on the PERC Mentor to facilitate them learn the percutaneous renal access skill. The novice group further attempted to perform percutaneous renal access using the same case scenario thrice (posttest). Differences between the posttest and pretest objective parameters demonstrated the acquisition of skill by the novice group.

Fourth exercise

After the training on the PERC Mentor, the five novices (who had performed the task in pig initially) repeated the same task on pig (posttraining skill). The analysis of the baseline puncture skill and the posttraining skill demonstrated the predictive validity of the simulation exercise.

Statistical analysis

Statistical analysis was done using Student's *t*-test to establish the level of significance (p-value less than 0.05 was considered statistically significant). The analysis between the groups was done by calculating the average (mean ± standard of errors) of the stored data on PERC Mentor and recordings of data by an observer on the porcine model.

Results

Only the participants with complete data evaluation on all possible validity tests were considered for final analysis. A total of 56 participants performed the training in the wet and dry laboratories, and complete data evaluation of only 24 was available. There were few experts and novices who did one aspect of validity testing and failed to complete the next validity testing on PERC Mentor. In addition, there were two novices who took the baseline assessment of access skill on the porcine model. They completed the PERC Mentor validity test but were unavailable to perform the predictive validity testing on the porcine model because of some unavoidable circumstances. The results of such participants were excluded from the final analysis to avoid test result bias.

Face and content validities

The overall useful appraisal was 4 in a scale of 1 to 5 (1 is poor and 5 is excellent). Simulation complexity and graphics on VR were understood by majority of experts. All experts

Table 2. Construct Validity (Experts and Novices)

Data parameters studied	Expert (n = 9; mean ± SEM)	Novice (n = 15; mean ± SEM)	p-Value
Total time (seconds)	187 ± 26	222 ± 29.6	0.005[a]
X-ray exposure time (seconds)	118 ± 18.7	123.3 ± 19.40	0.27
Total time spent introducing needle to collecting system (seconds)	13.1 ± 3.1	18.9 ± 2.5	0.0001[a]
Number of attempts to puncture the collecting system	2.00 ± 0.20	2.8 ± 0.4	<0.0001[a]
Perforations (number of occurrences)	1.3 ± 0.2	1.5 ± 0.4	0.07
Total amount of retrograde contrast injected (mL)	62.7 ± 7.7	67 ± 7.9	0.11

[a]Statistically significant ($p \leq 0.05$).
SEM = standard error of means.

Table 3. Acquisition of Skills (Novices)

Data parameters studied	*Novice pretest (mean ± SEM)*	*Novice posttest (mean ± SEM)*	p-*Value*
Total time (seconds)	222 ± 29.6	42.7 ± 6.8	<0.0001[a]
X-ray exposure time (seconds)	123.3 ± 19.40	66.9 ± 10.20	<0.0001[a]
Total time spent introducing needle to collecting system (seconds)	18.9 ± 2.5	17.30 ± 2.9	0.08
Number of attempts to puncture the collecting system	2.00 ± 0.20	1.3 ± 0.10	<0.0001[a]
Perforations (number of occurrences)	1.3 ± 0.2	0.8 ± 0.3	<0.0001[a]
Total amount of retrograde contrast injected (mL)	67 ± 7.9	33.20 ± 3.6	<0.0001[a]

[a]Statistically significant ($p \leq 0.05$).

had consensus of PERC Mentor as being an excellent training tool for urology trainees. Most of the experts still had doubts of considering it as an assessment tool and would prefer further validation studies to reach a conclusion. Overall face validity is summarized in Table 1.

Construct validity

The results of univariate analysis between the experts and novices are given in Table 2.

Univariate analysis showed that experts were significantly faster in performing the task, had reduced time in introducing needle in the collecting system, required fewer attempts to puncture the collecting system, and had lesser number of perforation. Although the perforations were less in the expert group, it could not translate into the statistical significance. This may be due to large variation in the standard deviation observed between the experts or could be due to the less participant numbers.

Acquisition of percutaneous renal access skills

After the PERC Mentor training (Table 3), novice demonstrated statistically significant improvement in reducing the total procedural time and fluoroscopy time, decreasing the number of attempts to puncture the collecting system and the number of perforations, and finally, the total amount of retrograde contrast used was also reduced.

Predictive validity

In the untrained group, only one novice was able to achieve access. There were three major complications (infundibular tear, extravasation, and vessel injury one each) by different novices. Four novices abandoned the procedure after a mean attempt time of 36 ± 13 minutes. All the trainees after the training session on PERC Mentor were able to achieve access. There was no operative complication noted in the posttraining novice group (Table 4).

Discussion

The ideal teaching aid for a novice is hands-on training on the live patients. However, there are many ethical issues for consideration in the current traditional teaching, such as the devastating complications that can occur in the early learning curve, cost, and paucity of cases for hands-on training. The next ideal substitute is training on a live anesthetized animal model. It relays the exact anatomy and has the advantage of the tissue feel for training, for example, percutaneous access. Limitations for using animals for training include recurring expense of the animal, radiation and occupational hazard to the trainees, requirement of a skilled veterinary assistant, anesthesia setup in the laboratory, and finally, legal permission from the animal ethics committee. To overcome these hurdles, a need is felt to train the novice in a bench model before hands-on intraoperative training on live subjects.

Rapid developments in computer technology have allowed computer-based system to simulate endoscopic procedure more realistically, including complications. Although it is true that acquisition of skill with live patients cannot be completely replaced by simulator training, a simulation model experience is required for refining techniques and tactics. This experience can be transferred from senior urologists to residents to fine tune the skill without harming patients.[3] Before the novice is trained sufficiently in the simulator model, an assessment test can point the deficiencies in a trainee of a particular aspect, which can be corrected further. The subjective assessment possesses poor test–retest reliability and can also be affected by poor interobserver reliability.[4] Objective assessment is essential because deficiencies in training and performance are difficult to correct without objective feedback.[5] In an international workshop, a group of experts

Table 4. Predictive Validity (Novices)

Novice	*Baseline success*	*Baseline complication*	*Time to baseline access (minutes)*	*Posttraining success*	*Time to access (minutes)*	*Posttraining complication*
1	No	—	NA	Yes	14	—
2	No	Extravasation	NA	Yes	8	—
3	Yes	Infundibular tear	24	Yes	6	—
4	No	Vessel injury	NA	Yes	11	—
5	No	—	NA	Yes	5	—

NA = not achievable.

Table 5. Current Published Series of Percutaneous Renal Access Training

Reference	*Teaching technology*	*Measured parameters*	*Inclusion criteria*	*Content validity*	*Construct validity*	*Face validity*	*Predictive validity*	*Improvement of skill after training*
Knudsen et al[14]	Virtual reality	GRS; data metrics	Novices and experts	+	++	+	Not done	++
Margulis et al[15]	Virtual reality	GRS	Trained and untrained novices	Not done	Not done	Not done	++	Not done
Park et al[16]	Virtual reality	GRS; data metrics	Novices and experts	+	++	+	Not done	Not done
This study	Virtual reality	GRS; data metrics	Novices and experts	+	++	+	+++	+++
Hammond et al[10]	*Ex-vivo* porcine (high-fidelity bench)	GRS	Novices	+	Not done	+	Not done	Not done
Häcker et al[12]	*Ex-vivo* porcine (high-fidelity bench)	GRS	Not done	+	Not done	+	Not done	Not done
Strohmaier and Giese[11]	*Ex-vivo* cadaver porcine (high-fidelity bench)	GRS	Experts	+	Not done	+	Not done	Not done

Plus symbols reflect a relative depth of assessment (the greater the number of +, the more strictly the assessment was done).
GRS = global rating scale; data metric = stored data from the software.

reviewed all methods of assessment and suggested parameters that should constitute output metrics for the assessment of technical skills.[6]

This study is an attempt to evaluate the validity of PERC Mentor in training percutaneous renal access. Currently, there are few published series that evaluate the training of percutaneous renal access (Table 5). Bench models sacrifice fidelity for safety, availability, portability, and reduced cost.[7] The utility of the bench model has been demonstrated in other than percutaneous access training. Anastakis et al[8] demonstrated that surgical skills learned on bench models were transferred appropriately to human cadavers. Seymour et al[9] studied the positive aspects of predictive validity of a high-fidelity simulator to the clinical setting. The main drawback of the available bench models[10–12] is their lack of validation process. They are single-center published series assessing only face and content validities. Further, bench models lack the tactile sensation of puncturing the flank and providing a representative target that can be accessed.[10]

On the contrary, VR-based PERC Mentor has higher fidelity and more capacity for assessment and feedback. The performance of a task can be assessed in many ways. The time to complete a procedure is one potential end point; however, many important elements of a good surgeon would not be fully evaluated and incorporated into a time score.[13] Therefore, interpretation requires analysis of the multiple stored data metrics and evaluating different aspects of a given task.

Although such devices are costly (up to 50,000 euros), they have several advantages over bench or cadaver models. The biggest safety concern of radiation is not present. Percutaneous access can be practiced without consideration to subject limitation. Whole learning atmosphere changes from an intimidating operation theater to a learner-friendly cartoon-like environment. The training is completely complication free, with no ethical concern for patient safety.

To our knowledge, this is the first report incorporating different validities in a single study of VR percutaneous renal access. Knudsen et al[14] studied the test–retest reliability and acquisition of skills and found that students trained on the VR simulator demonstrated statistically significant improvement on repeat testing. Margulis et al[15] studied the positive predictive validity for novice performance on the porcine model after simulator training. Park et al[16] studied face, content, and construct validities on a standard case scenario using PERC Mentor and found it to be a useful teaching tool that differentiates novices with experts easily.

Although predictive validity implies correlation of VR performance with actual performance of the task, assessment of the trainees in a true clinical setting is neither ethical nor practical. The ideal predictive validity to translate VR skills into clinical percutaneous access proficiency has not been demonstrated. Moreover, inherent variability of the human model precludes standardization of the assessment. We used a porcine model to replicate live surrogate for assessment of predictive validity as has been demonstrated by Margulis et al.[15] For novice, performance on the porcine model after simulator training predicted operative improvement. Face, content, and construct validities were assessed between the experts and novices. The experts were asked to complete a questionnaire covering five domains of face validity to determine whether the test was appropriate and a reasonable representative of the percutaneous access skill. The results matched with those of Park et al,[16] suggesting it to be a realistic and useful training model for educational purposes. For acquisition of skills, our results showed that the students trained on the VR simulator demonstrated statistically significant improvement on repeat testing. To our surprise, many posttest values obtained after PERC Mentor training in the novice group were better than the construct validity value obtained for the experts. This could be explained by the fact that the learning may have been due to the consequence of repetition of the same task adding test–retest reliability error. However, the skill acquisition demonstrated in the porcine model proved that there was a definite learning of the skill, rather that test–retest reliability.

The critique of the study may be that technical skill is not the goal in surgery but the minimum requirement. The current teaching goal that a trainee must complete to demonstrate fitness for independent practice is not a measure of excellence but a measure of competence. It seems appropriate to include a measure of technical skill because this, in addition to knowledge and decision making, is required to function as a urologist.[17] VR training by itself is unable to override the impact of clinical training, although it may help shorten the learning curve early in training. Another issue with the inclusion of technical skill assessment in the teaching curricula is the type of skill to be assessed. Should there be an exercise to evaluate basic skills, such as percutaneous access, or the ability to perform a complete procedure, such as a PCNL?

Conclusion

PERC Mentor offers a realistic simulation of percutaneous renal access encountered in clinical practice. Experts perform the access skill faster than novice even on VR. For novice, VR practice results in improvement in access skill.

VR training enhances the operating room performance in the early learning curve for the novice. Although the simulation is costly, it has several advantages over bench or cadaver models. VR training has the potential to become a standard tool for clinical education. In the near future, a wider distribution will allow multicenter trials to evaluate the effects of simulator training.

Disclosure Statement

No competing financial interests exist.

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Abbreviations Used

GRS = global rating scale
NA = not achievable
PCNL = percutaneous nephrolithotomy
SEM = standard error of means
VR = virtual reality
PCN = percutaneous nephrostomy

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