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Simulation Training in Interventional Radiology

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DISCLOSURE

- No conflict of interest to declare on behalf of the presenter and research team
1. Introduction to simulation training
2. Identification of Interventional Radiology procedural and non-procedural skills taught using simulation technology
3. Description of education validity of commercially available simulation technologies
4. Review of assessment tools applied in simulation training
SECTION 1: INTRODUCTION
SIMULATION CENTERS AROUND THE WORLD

**EVE Real-time high-fidelity Endovascular Simulator** for real-time interventional neuroradiology at Massachusetts General Hospital, The Sim Group (Cambrige, MA, United States)

**PERC Mentor Simbionix** for percutaneous nephrostomy access under real-time fluoroscopy at The Chaim Sheba Medical Center, MSR, the Israel Center for Medical Simulation (Tel Hashomer, Israel)

**Ultrasound guided peripherally inserted central catheter cannulation Simulator** at McMaster University, Centre for Simulation-Based Learning (Hamilton, ON, Canada)
Increased pressure on the healthcare system to be safer and more efficient

<table>
<thead>
<tr>
<th>Problem</th>
<th>Solution</th>
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<tr>
<td>Safety of patient is paramount</td>
<td>Train in a risk-free environment without real patients</td>
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<tr>
<td>Time constraints on training</td>
<td>Training can be tailored to a learners pace</td>
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<td>Training can be self-directed or part of a curriculum</td>
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<td>Lack of uniformity in training</td>
<td>Wide range of training cases available</td>
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DEFINITIONS

- Simulation: “devices, life-like virtual environments and contrived social situations that mimic problems, events or conditions that arise in professional [medical] encounters”\(^1\)
- Procedural skills: practical physical skills performed by a physician to complete a medical procedure
- Non-procedural skills: skills not associated with a medical procedure but are integral to medical practice such as interpersonal, cognitive and personal resource skills
- Simulators
  - Virtual Reality – immersive computer programs which recreate the real world
  - Mannequins – more specifically Computer-Enhanced Mannequins, full body models with computer systems which can replicate physiological responses
  - Phantoms or Part-Task Trainers – model of an anatomic region used for teaching a specific skill
  - Computer-Based Learning – digital simulations on a computer
SECTION 2.1: SIMULATION TRAINING OF PROCEDURAL SKILLS
PROCEDURAL SKILLS TRAINED ON SIMULATORS

- Ultrasound Guided Liver Biopsy
- CT Guided Biopsy
- Ultrasound Guided Needle Procedures
- Ultrasound Guided Peripherally Inserted Central Catheter (PICC) Cannulation
- Ultrasound Scanning and Interpretation
- Transvaginal Ultrasound
- Focused assessment in sonography for trauma (FAST)
- Seldinger Technique for Vascular Catheterization
- Percutaneous Transhepatic Cholangiography
- Ablation of Liver Tumors
- Fluoroscopy Guided Lumbar Puncture
- C-Arm Training
- Stenting
- Angioplasty
- Cannulation
- Endovascular Ruptured Aortic Aneurysm Repair (rEVAR)
- Catheterization
- Percutaneous Coronary Revascularization
- Palpation and Needle Insertion
- Contrast Reaction, Sedation and Analgesia Management
ULTRASOUND PROCEDURES

- Ultrasound needle guided procedures\(^2\)
  - Needle insertion phantom (Advance Medical Technologies LLC, Kirkland WA)
  - US machine used to guide the needle to target

- Ultrasound Scanning and Interpretation\(^3\)
  - UltraSim by MedSim ultrasound simulator used with mannequin to generate simulated US images
Virtual Reality

- ImaGiNe Seldinger has 2 stations
- 1st station: needle puncture
  - Needle inserted into mannequin with a simulated pulse and haptics device for needle feedback
  - User wears 3D stereoscopic glasses to see anatomical overlay on mannequin.
- 2nd station: catheterization
  - Real guidewire and catheter inserted into simulated skin model
  - 2 haptics devices give feedback for needle holder and tool insertion
  - LED light blinks when vessel is punctured
  - Computer displays simulated fluoroscopy images generated from real patient data
MICROWAVE ABLATION OF LIVER TUMORS

- Virtual Reality
  - Computer displays US images created from CT data
  - Simulated US probe and microwave antenna used with abdominal phantom (CIRS 071, Elkhart, IN, USA)
  - Program localizes and displays probe and needle on US images
C-ARM TRAINING

- Computer Based Training and Virtual Reality
  - VirtX teaches user how to use a C-arm to reduce dose to patient and medical team
  - Computer based mode allows user to move c-arm, patient and table using the program interface to complete task by taking DRR image
  - Virtual reality mode allows user uses computer program, rayless c-arm, mannequin and table to complete task
STENTING

- Procedures: Renal, Iliac, Carotid,
- Virtual Reality
  - Procedicus-VIST by Mentice⁸,⁹,¹⁰
    - Mannequin with haptics devices in femoral access point allows insertion of modified tools
    - Computer screens display fluoroscopic images and virtual tools
    - Joystick for user to move virtual fluoroscope, zoom, replay and capture images, and move the table
    - Foot pedals and control panel for control of the fluoroscopy suite
    - Use of extra modules to simulate the injection of contrast, perform angioplasty, deploy stents, and perform fluoroscopy with digital subtraction angiography
  - AngioMENTOR by Simbionix⁹
    - Desktop for displaying simulated fluoroscopic images
    - Haptics module for real tool insertion
    - PROcedure program by Simbionix can use real patient data to generate images
ANGLIOPLASTY

- Procedures: iliac artery, renal artery, superficial femoral artery, coronary\textsuperscript{11,12,13,14}
- Virtual Reality
  - Procedicus-VIST
  - AngioMENTOR
  - ICTS\textsuperscript{27}
    - modified instruments inserted into haptics module
    - VR module displays patient ECG and other vital sign data
    - fluoroscopy images made from CT data and Visible Body Project anatomy
  - NeuroCath\textsuperscript{28}
    - uses real patient data to displays 3D and fluoroscopy images
    - program allows user to choose tools and insertion point
    - control panel to manipulate table and a haptics device for catheter insertion
CANNULATION

- Procedures: renal arteries, superior mesenteric, internal carotid
- Virtual Reality
  - In-house simulator called VPAS (videoscopic phantom based angiographic simulation for fluoroscopic cannulation of arterial tree vessels)
  - User cannulates a silicon phantom with mechanical blood flow system
  - Camera records phantom and display as fluoroscopic images to guide user navigation since phantom is hidden from view
CATHETERIZATION

- Procedures: cardiac, carotid, subclavian, ascending aorta, renal\textsuperscript{16,17,18}
- Virtual Reality
  - Procedicus-VIST
  - STRESS simulator
    - User views screen which merges an X-ray image with video of glass phantom
    - Phantom model of abdominal aorta, renal and iliac arteries
    - User inserts guidewire and catheter into phantom
    - Program’s injection option simulates contrast injection
  - In-House simulator\textsuperscript{19}
    - User inserts tools into homemade haptics device
    - Real CT images used to create 3D images of vasculature
Virtual Reality
- daVinci\textsuperscript{20} used for patient-specific treatment planning and IR device testing
- Uses CT and MRI data to reconstruct images
- Guidewires and catheters are inserted into haptics device which can be integrated with a mannequin interface
- Computer screen shows fluoroscopic images or 3D views so user can see vasculature
- User can make endoscopic views and save "vascular roadmaps" created during contrast injection
- VR program has contrast injection, balloon inflation, stent and coil replacement options
Virtual Reality
  o Palpsim
  o User views LCD screen which displays their hands and real needle overlaid on a simulation of a patient's back
  o Hands and tools are tracked using 2 cameras
  o User inserts needle into haptics device and palpates a silicon gel skin phantom with embedded pulsation device
Computer Based Simulation
  - SAC Computer simulator\textsuperscript{22}
    - Computer program where user must save patient undergoing contrast reaction by controlling the airway, breathing, circulation and administering medication
    - Interface displays state of the airway (placement of nasal oxygen, face mask, anesthetic mask or intubation) and vital sign monitors
    - Expert help option in program
  - Sedation Simulator by Anesoft\textsuperscript{23}
    - Computer program where user is the sedation provider and must save patient undergoing sedation reaction
    - User can manage the airway and breathing, administer fluids and drugs, interact with the radiologist performing the procedure and resuscitate the patient if necessary
    - Interface displays patient’s history, vital signs and patient response

\textbf{SAC program interface}

\textbf{Sedation Simulator program interface}
• Mannequin
  • SimMan by Lauderal\textsuperscript{24,25,26,27}
  • Mannequin can simulate tongue edema, laryngospasm, and bronchospasm with audible wheezing
  • Displays vital signs (HR, BP, PO2 and breathing rate) which change dynamically
  • Speech controlled by a technician who can make the mannequin respond to user interaction
  • User can administer injections, intravenous lines, nasal cannula and oxygen masks
SECTION 2.2: SIMULATION TRAINING OF NON-PROCEDURAL SKILLS
CRISIS MANAGEMENT

- Mannequin
  - SimMan\textsuperscript{28,29,30}
    - In-situ simulation at a hospital involving nurses, doctors, etc.
    - Manage a cardiac arrest, contrast reaction and biopsy complications
  - Patient Simulator by Eagle Simulation\textsuperscript{31}
    - Simulation resembles a patient in a CT scanner radiology suite
    - Mannequin has radial and carotid pulses, pupillary and lid reflexes, temperature changes,
    - Breathing, heart sounds and voice controlled by technician
    - Mannequin responds semi-automatically to user
    - Users work in teams to manage reaction with IV placement and medication administration through brachial, antecubital, or forearm veins
HOSPITAL NAVIGATION AND TASK PRIORITIZATION

- Computer based simulation\(^{32}\)
  - Night Shift computer game
  - User is a resident on duty at night and must respond to different tasks in priority order
  - Events are calibrated to reflect actual frequency and severity as recorded in NHS database
  - During the game tasks deteriorate and go up in priority
  - Actual floor plan of hospital incorporated into program allows users to learn hospital layout while playing
SECTION 3: EDUCATIONAL VALIDITY
FACE VALIDITY

- Definition: how well a simulation/simulator mirrors real life

- Coles, John et al. (2011)²¹
  - Femoral palpation and needle insertion on Palpsim VR simulator
  - 7 interventional radiologists with 5+ years of experience
  - 29 point questionnaire on realism of the simulation rated using Likert scale
  - Results
    - High sense of immersion
    - Realistic draping, pulse and location of femoral artery
    - Insertion device had good haptic feedback
    - “Feeling of free space” was distorted when using the needle
Definition: how well a simulation measures the knowledge it intends to measure; does it train the skills it is supposed to.

Nicholson, Cates et al. (2006)

- Left and right carotid angiography on Procedicus-VIST
- 100 interventionalists with a mean of 12.4 yrs of endovascular experience
- Survey to evaluate anatomy, tools, and overall procedural steps on 5-point Likert scale
- Results
  - Good aortic and carotid anatomy but poor cranial anatomy
  - Realistic haptics and feedback from tools
  - Graphics appeared similar to real fluoroscopic images
  - Simulation contains all necessary procedural steps
  - Simulator allows user to make mistakes

<table>
<thead>
<tr>
<th>TABLE 1. Mean evaluation scores and standard deviations of physicians’ assessments of individual qualities of simulated carotid angiography with the VIST</th>
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<tr>
<td>Anatomy</td>
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<td>Carotid arteries</td>
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<td>Overall procedure</td>
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<td>Fluoroscopic views</td>
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<tr>
<td>Intravenous contrast appearance</td>
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<tr>
<td>Cineangiogram realism</td>
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<td>Table controls</td>
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<tr>
<td>Overall procedure</td>
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</table>

All scores are based upon a five-point Likert scale applied to how realistic the evaluator felt the simulator represented the actual procedure (1 = not realistic and 5 = very realistic).
Definition: how well a simulator measures the skill it is supposed to measure; differentiation based on skill level

Van Herzeele, Aggarwal et al. (2007)

- Procedicus VIST used to perform angioplasty and stenting of right ICA with type 1 arch and stenosis in proximal region
- Study assessed simulator metrics: procedure time, contrast volume, number of angiograms performed, fluoroscopic time, # of catheter errors and procedure-specific errors
- 45 interventionalists from radiology, vascular surgery and cardiology:
  - Group A (0 CAS procedures), n=12
  - Group B (1 to 20 CAS), n=12,
  - Group C (21 to 50 CAS), n=10
  - Group D (>50 CAS, experienced group), n=11

- Results
  - Fluoroscopy time, procedure time and number of angiograms were valid metrics to differentiate between experienced and inexperienced groups; not able to differentiate between inexperienced skill levels
  - Error metrics did not show statistical significance for skill level differentiation

CONSTRUCT VALIDITY
Definition: how well simulation can train someone as compared to a validated method\(^8\)

Mendiratta-Lala, Williams et al. (2015)\(^36\)

- Evaluated knowledge using pre and post MCQ test after receiving training on percutaneous noncontinuous CT-guided fluoroscopic procedures using in-house phantom and web-based training module
- 40 radiology residents and 8 expert IRs
  - Group A - IR experts
  - Group B - 4th year residents without simulation training
  - Group C - 2nd and 3rd year residents with simulation training and residency
  - Group D - 1st year residents without residency and only simulation training

Results
- Pre-test results were related to level of experience: B>C>D
- Post-test results
  - Group C score increase was statistically significant
  - Group D score approached Group B pre-test score
- Suggests simulation training enhances knowledge comparable to residency training
**PREDICTIVE VALIDITY/ TRANSFERRENCe**

- Definition: how well skills trained on a simulator translate to the operating room; can performance on a simulator predict performance in OR

- Chaer, Derubertis et al. (2006)
  - Mentice Procedicus-VIST used for simulation course
  - 2 catheter based procedures for lower extremity occlusive disease in OR
  - 20 residents on surgery rotation with no endovascular experience: 10 enrolled in simulation course and apprenticeship training, other 10 only received apprenticeship training
  - Blinded expert evaluated the procedures using a procedural checklist with rating scale (18 steps) and an overall performance global rating scale (12 criteria)

- Results
  - Simulation group got higher scores on procedural checklist and global rating scale
  - 2nd procedure showed more statistic significance on checklist score for simulation versus control group
  - Overall performance of 1st and 2nd operation did not change within groups
SECTION 4: ASSESSMENT TOOLS
SIMULATOR METRICS

- Assessment metrics generated by the simulator
- Pros: objective, when used with other assessment methods can be robust
- Cons: metrics are not always valid or designed with medical knowledge, need an expert dataset as benchmark
- Johnson, Hunt et al. (2012)\(^{38}\)
  - US guided biopsy on VR in-house simulator designed using critical procedural steps from task analysis created with expert consultation
  - 14 IRs and 26 trainees tried procedure on simulator
  - Experience level led to significant differences in scores for targeting, probe usage time and mean needle length in beam
  - Experienced participants received better overall scores from simulator
PROCEDURAL CHECKLISTS

- Assess procedural skills using a binary score or rating scale
- Used for in-situ or post-hoc video assessment
- Pros: objective scoring method, effective, reliable and validated method of assessment
- Cons: subjective design, does not take into account timing and sequence of actions
- When used in conjunction with global rating scales it does not add any additional value to assessment
- Bagai, O’Brien et al. (2012)\textsuperscript{17}
  - 27 trainees on cardiac catheterization rotation
  - Randomized into control and simulation group by residency year
  - Simulation group got proctored training of cardiac catheterization on Procedicus-VIST
  - Pre-test and post-test 1 wk later on VIST
  - Evaluated using procedural checklist with rating scale
  - Change in pre test and post test score was significantly higher in simulation group versus in control group
Rating of general criterion of whole performance usually using Likert rating scale

Pros: rating proven to be tied to experience, good reliability

Cons: generic, inter-rater reliability needs to be considered, training needed for raters to use tool

Willaert, Aggarwal et al. (2011)\textsuperscript{37}
- 33 endovascular physicians with varying level of experience with CAS procedures
- 3 groups: highly experienced, moderately and novice
- VR Simulator AngioMENTOR
- Procedure on simulator recorded and scored using Generic Endovascular global rating scale (GSR) tool and a procedure specific rating scale (PSRS)
- Experienced physicians had higher GSR scores, this was less significant using PSRS
- GSR and PSRS score was not significant between the highly and moderately experienced groups
Generally used for subjective assessment:
- Evaluating face validity
- Confidence in skills
- Utility of simulation experience
- Measured on Likert scale or open-ended answer

- Procedural and non-procedural skills
- Wang, Schopp et al. (2011)²⁷
  - Contrast reaction management simulation with 44 radiology residents: 23 randomized into simulation group
  - High fidelity simulator using SimMan
  - Survey of comfort managing contrast reactions before and after simulation
  - Simulation group reported higher comfort levels after training
**PRE AND POST TESTS**

- Primarily used for knowledge assessment
- Use same or different pre and post test
- Generally MCQ format
- Mendiratta-Lala, Williams et al. (2010)$^2$
  - 29 radiology residents participated in US needle guided procedural training
  - Proctored and self-directed training on part task trainer for 6 months
  - Improvement in pre test and post test score was statistically significant

### APPENDIX A. SAMPLE PRETEST AND POSTTEST QUESTIONS

1. Which needle is used for fine-needle aspiration?
2. Which needle is used for core biopsy?
3. What is Seldinger technique?
4. What is trochar technique?
5. Regarding core biopsy procedures, which of the following is false?
6. Which of the following is true regarding a coaxial system?
7. All of the following are true regarding fine-needle aspiration, except?
8. All of the following are true regarding core biopsies, except?
9. If too much fluid is removed during a thoracentesis, what is the potential complication?
10. All of the following are true regarding coagulation/bleeding complications, except?
11. Which of the following is not an indication for ultrasound-guided thoracentesis/paracentesis?
12. The proper needle entrance into a breast lesion under ultrasound guidance is?
13. Which of the following can be safely crossed when performing a percutaneous procedure?
14. Advantages of ultrasound-guided procedures over computed tomography-guided procedures include all but which of the following?
15. Visualization of needle tip can be improved by all of the following except?
TIME ACTION ANALYSIS

- Used to assess procedural skills
- Breaks down a procedure into a series of steps and how long each one takes
- Pros: objective analysis
- Cons: lots of set up for videotaping, time needed for video analysis, time taken does not equal quality
- Duncan, Kline et al. (2007)\(^{39}\)
  - Renal stenting procedure performed on AngioMENTOR and Procedicus-VIST
  - 10 experienced angiographers and IRs
  - Procedure videotaped and analyzed by blinded reviewers with no angiography experience
  - Procedural steps outline used to determine placement of time-points in video
  - Efficiency score calculated using: procedure time, contrast use, fluoroscopy time and supply use
  - All participants met efficiency standards
ERROR ANALYSIS

- Rating of performance based on number and types of errors made
- Good for differentiating skill level
- Need to define and weight types of errors
- Klass, Tam et al. (2008)\textsuperscript{10}
  - Left renal artery angioplasty performed on Procedicus-VIST
  - 12 new radiology residents
  - Access to simulator to practice during 1st year of residency
  - Experts noted the following errors: incorrect selection of equipment, incorrect use of equipment and incorrect selection of the next appropriate stage of the task.
  - Group data shows errors did not decrease over the 3 trials
  - Individual data shows some participants did decrease the number of errors made over the 3 trials
  - Common mistakes were lack of familiarity with the equipment and skipping procedural steps
Simulation has the potential to revolutionize clinical skill training because it provides a risk-free, uniform, accessible medium to train a wide variety of procedural and non-procedural skills.

This potential can be hindered by sparse and non-uniform evidence of educational validity of commercially available simulation technology.

- Face validity of simulators is easy to assess and many commercially available simulations have been validated.
- The ultimate goal in simulation research is to prove predictive validity/transference; this will lead to widespread implementation.

A wide variety of assessment tools exist to measure knowledge and competence of trainees.

- When designing a simulation training exercise, it is important to choose an appropriate assessment tool to accurately measure the skill being trained.
REFERENCES