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Interventional radiology core skills simulation: mid term status of the CRaIVE projects

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1. Purpose

The aim of this project isto develop Interventional Radiology (IR) simulator models for core skills training.

Background. There is a shortage of radiologists trained in performance of [Interventional radiology uses imaging to guide minally invasive procedures] IR procedures. Visceral and vascular IR techniques almost universally commence with a needle puncture, usually to a specific target for biopsy, or to introduce wires and catheters for diagnosis or treatment. These skills are learnt in an apprenticeship in simple diagnostic procedures in patients, though there are [Apprenticeship training: the drawbacks] drawbacks to this training method[1,2]. In addition, certification depends partly on a record of the number of procedures performed, with no current method of objective IR skills assessment.

Despite the presence of an effective mentor, the apprenticeship method of training presents some risks to patients: these could be mitigated in a [Pre-patient training.] pre-patient training curriculum, which would use [Simulation] simulationto provide skills training [3].

[Applications of Computer Based Simulation] Computer based simulationis just one of a range of [Simulations for training] alternativesto apprenticeship training, which include physical and animal models, and rapid prototyping models to train catheterisation skills. Fixed models are expensive, lack physiology, have fixed anatomy and are destroyed by repeated needle puncture. Animal models have anatomical differences, lack pathology and, in the UK, political acceptability.

Realistic Virtual Environments (*VEs)*[DICOM data as a basis for creating virtual environments.] can be derived from imaging data, with potential to introduce *physiological processes,tissue deformation*and [Haptics devices] *haptics*(touch).Patient anatomical variability and pathology can be obtained from multimodality (MR, CT) imaging studies using a series of semi-automated processing steps to segment ('label' in 3D) the anatomical data.

There are existing computer based simulations of catheterisation and needle puncture procedures such as venepuncture, percutaneous nephrolithotomy, [Mediseus Epidural Simulation, MedicVision] epiduraland lumbar puncture and liver biopsy simulations [4-7]. Surgical virtual reality (VR) simulators for [Promis Simulator from Haptica in a skills centre setting] laparoscopic traininghave been shown to improve operator performance, though [A computer based simulation] vascular catheterisation simulationshave yet to convincingly transfer fine motor skills to procedures in patients [8]. Chaer et al have shown transfer of some cognitive and coarse motor skills using the VIST-VR (Mentice) endovascular simulator model, though the authors acknowledge that training in the randomised cohorts was not completely matched, and the observer based assessment tool used was unvalidated [9]; neither did the assessment tool evaluate fine motor skills.

Haptics have been shown to be important in influencing visual perception [10], and in the authenticity of a simulated procedure [11]. Yet in the main, fine motor skills transfer remains elusive, owing to limitations in simulator model fidelity and content. This inability to emulate low level operator actions represents a rate limiting step in attaining procedure simulations that reflect real world performance. Hence our aim in this project is to produce higher fidelity simulations in an attempt to model fine motor behaviours.

There is, currently, no validated VR model of [Ultrasound simulation using a laptop computer] ultrasound guided IR visceral needle accesswhere a trainee can experience the authentic 'feel' of a procedure, viewing realistic, variable case scenarios that take into account patient variability. This type of simulation is novel, but presents a range of technology challenges**.**

Accurate simulation requires incorporation of data from procedural *Task Analysis*into the development phase, including critical procedure steps and their metrics for *objective measures* of operator competence. Novel, *semiautomatic segmentation*of *patient specific imaging data* have been developed at Leeds and Imperial to generate anatomically realistic three dimensional VEs that reflect variability across patients.

[Haptics devices] Haptics in existing VR simulations of needle puncture are typically based on mathematical models and subjective assessment by experts. Work at Liverpool is providing *procedural force data*which will be used to validate our models and enhance the authenticity of the simulator.

*Validation:*Few, if any, simulations have been convincingly validated for training IR skills [12], though this should be achievable where content (replication of procedure steps) and fidelity (faithfulness of that replication) are appropriate to real world tasks [13]. Indeed correct reproduction of the task, and appropriate fidelity are the cornerstone of producing a simulation that has relevance to a particular training objective. In our projects, validation draws on the team's occupational psychology expertise (at University of Hull) [14] with evaluation by clinical radiologists at Liverpool, Leeds and Manchester. The simulator has been designed for use exclusively within radiology training curricula.

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2. Material and Methods

Ethics and research governance approvals were obtained for collection of procedural force and video records, as well as use of anonymous patient imaging data: these images are then uploaded to an.ftp server at Bangor University where they are available to the CRaIVE research team.

Task analysis: subject matter experts (SME) were identified by IR Societies (CIRSE, BSIR, SIR) for purposes of collecting video data from SME procedures, and subsequently inteviewing SME's to distil key procedure steps (cue perception, decision making, operator actions) [14]. To achieve this task analysis, [Video-recording procedures] video-recorded IR procedures performed by subject matter experts (SME), were [Part of a task analysis document.] decomposed by trained psychologists in operator interviews. A Wiki based web site was used to inform simulator design using an annotated task analysis. SMEs and computer scientists were able to input comments on the procedure steps, but particularly on the realisation of the analysis, and its derived content, in the simulation.

Force sensor pads were attached to the interventionist's fingers during IR procedures, with force data generated and recorded using a laptop computer [15]. Novel sensors have now been developed to record IR instrumentation forces and are geared to the dimensions of needles and guidewires.

Creating virtual environments. [DICOM data as a basis for creating virtual environments.] Relevant target anatomy and pathology in selected, anonymised, patient imaging studies was segmented and a surface and volume mesh, created. These data were also used to create simulated ultrasound images for needle guidance. Tissue deformations ([Kidney and liver penetration resistance modelling] needle insertion, intrinsic motion), calculated using a mass-spring algorithm, were mapped to human-computer interface devices.

Validation. Preliminary demonstration of integrated simulations to trainees and practitioners provided feedback.

3. Results

[Create virtual environment] Virtual environments (VEs) have been createdusing a range of segmentation methods (manual, semi-automatic, automatic), followed by mesh generation. [Immersive environment for needle puncture simulation: 3D-IW by SenseGraphics] Haptic devices(e.g. the [Catheter / wire haptics devices] Xitact [Mentice] wire/catheter haptic device) are mapped to the virtual environment using a [Simulation of wire / catheter] mass spring system.

Force studies: Intial work used capacitance pades (PPS, Los Angeles) to provide preliminary data. [Capacitance force sensor pads (PPS, Los Angeles)] This slide shows a waveform obtained during penetration of an arterial wall. It is probable that the needle tip is in contact with the arterial wall during what appears to be an approximately periodic waveform, occuing just before penetration of the wall. This pulsatile force may be detectable by an operator as a 'haptic cue'. Deformable models (see 'Virtual Environments', above) have incorporated data from these procedural instrument force measurements. Futher work is now progressing using novel sendors developed at Liverpool, and incorporating [Tracking during force data collection] motion trackingto identify the velocities of needles during penetration into tissues in vitro, as well as during actual IR procedures in patients.

Evidence based content. [Videorecording procedures] Task analysisinformed simulator development. Subject expert and technical input to this was obtained in a [Wiki format of task analysis] web-based, wikiformat. This input of computer scientists and IRs proves invaluable in simulator development.

Validation. Preliminary content validation studies yielded favourable observations, which are also driving revisions, including implementation of an [Needle puncture simulation with 3D viewing] immersive virtual environment, with haptic devices and [Immersive environment for needle puncture simulation: 3D-IW by SenseGraphics] stereoscopic viewing.

4. Conclusion

Virtual environments have been integrated into a novel framework for training ultrasound guided biopsy and the [An interim depiction of the Seldinger technique simulation.] Seldinger technique. We have described the evidence based development of these simulations, which is specific to training objectives in an IR curriculum. This work is guided by physical and cognitive analysis of the required task (performance objective). It uses real patient imaging data as the source of segmented anatomy, and thence the undelying virtual environment. The algorithms used within these anatomical data are informed by studies of procedural forces, provided the refining data required for realistic ‘feel’ in the simulations.

Review by subject experts has provided invaluable information in the form of repeated content validations, contributing to the re-design of each iteration and hence increasing relevance to the procedure in the real world.

Ongoing work includes review and refinement of the human-computer interface devices, novel segmentation methods, and further validation studies (construct, skills transfer).

[Come along to the Simulator Gallery at CIRSE 2008!] Thanks, and why not try out the simulator for yourself?

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6. Personal Information

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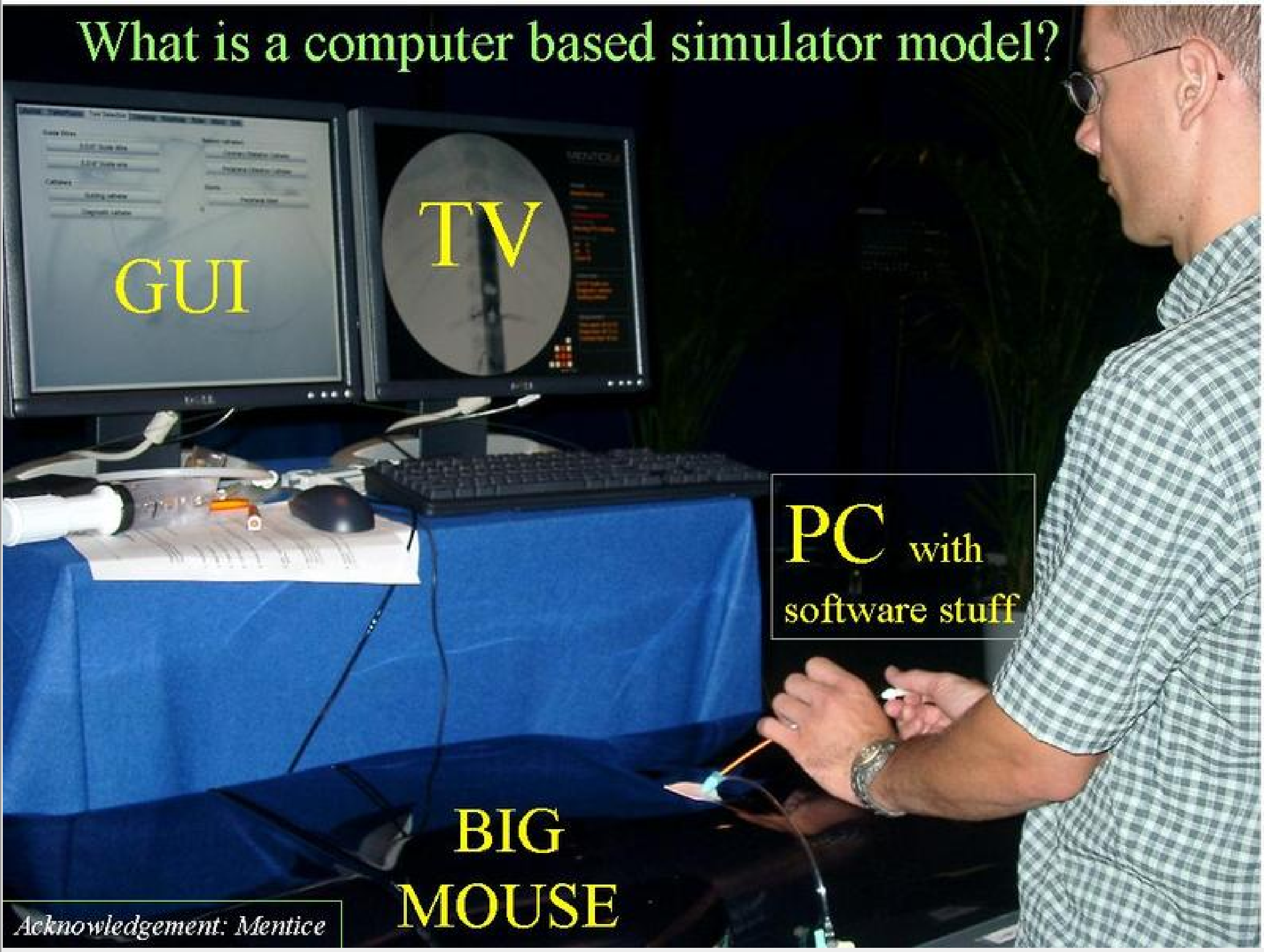
Project advisor: *Steve Dawson*, Harvard

Industrial partner: *MedicVision*

Project partner: *Virtalis Plc*

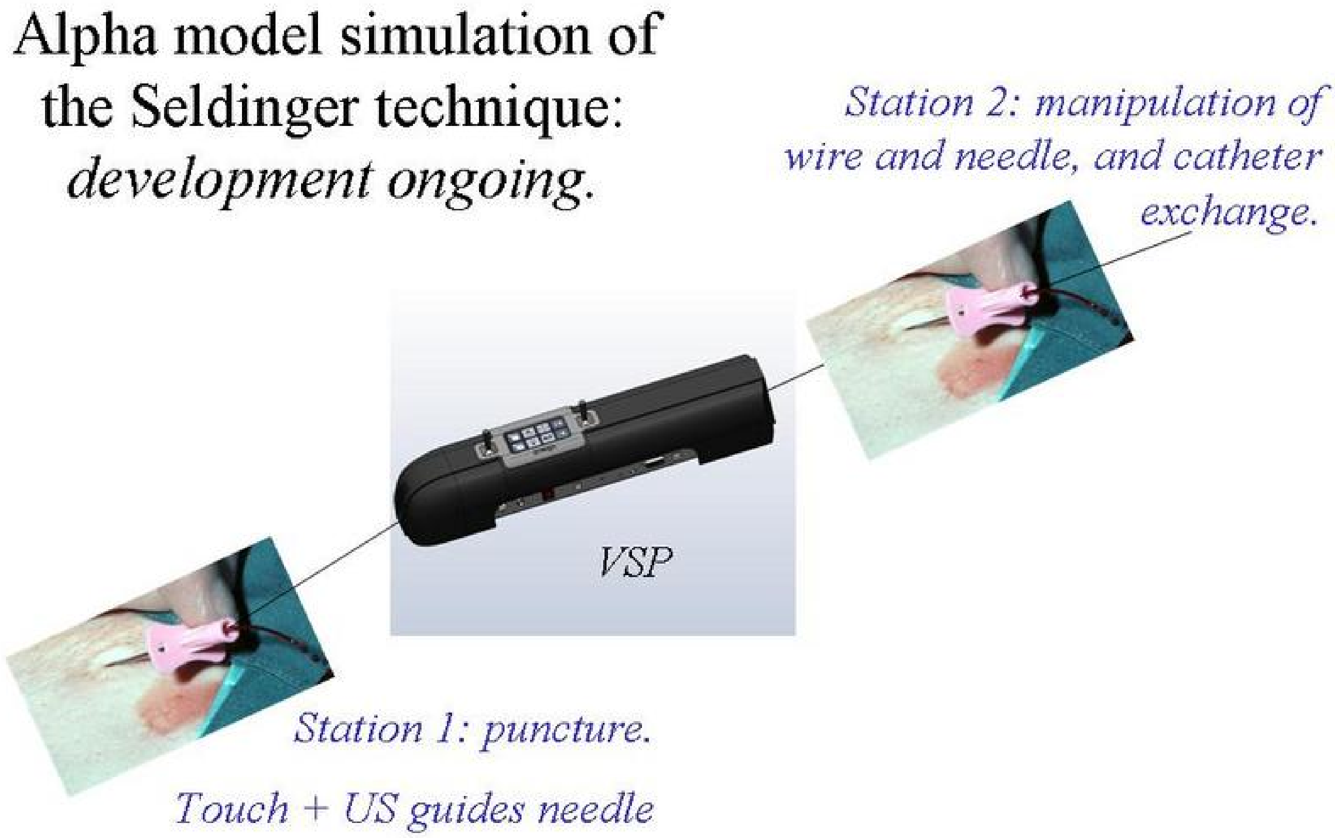
7. Mediafiles

A computer based simulation



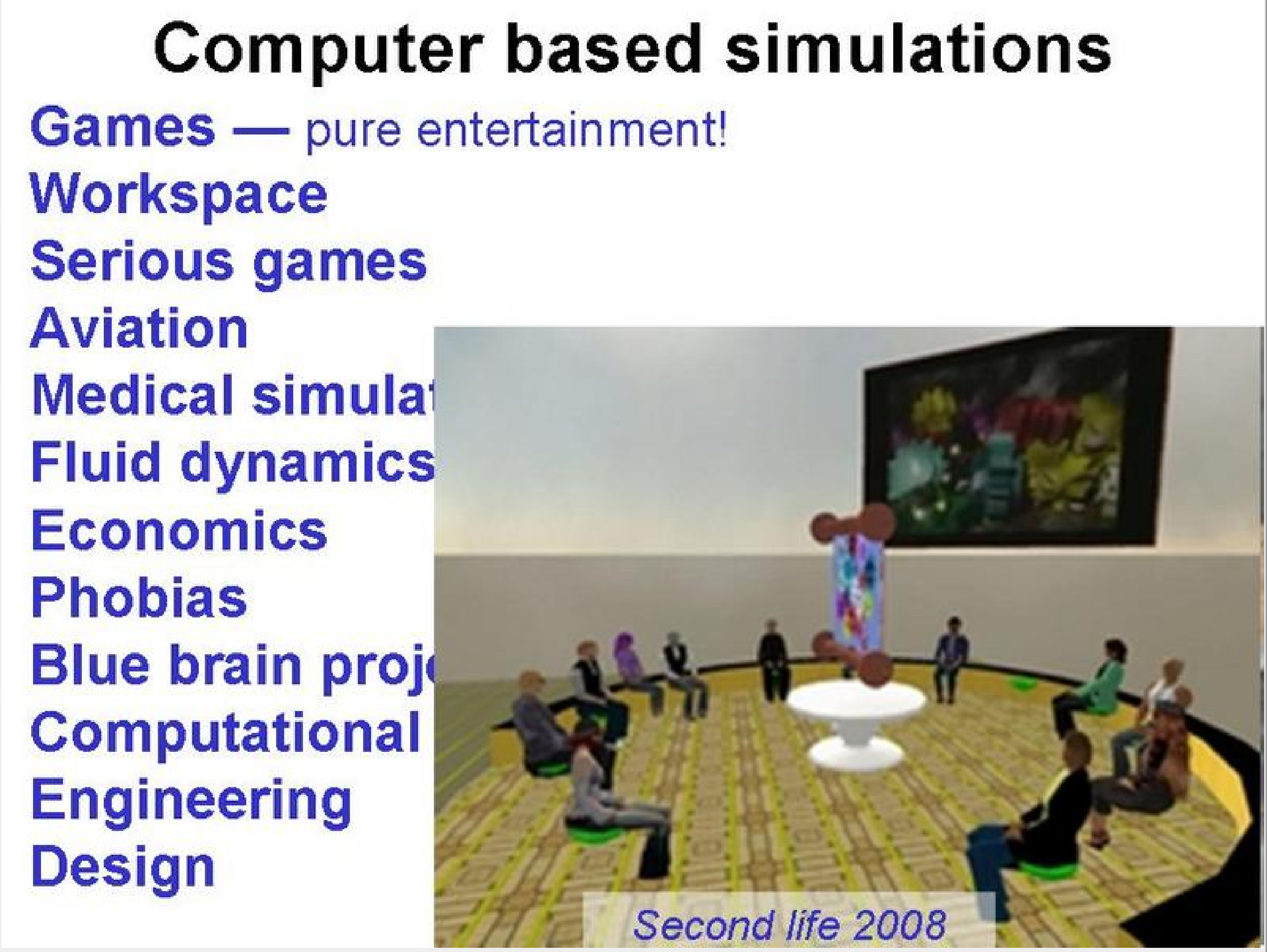
This is the Mentice VIst-VR simulation which uses a PC, a monitor and graphic-user interface, and a modified 'mouse' to deliver the 'feel' of a procedure: this is a haptics (=touch) device. The technology is very similar to that produced by the games industry. A medical training simulation, however, aims to replicate a task from the REAL world, and is subjected to validation for that specific training objective.

An interim depiction of the Seldinger technique simulation.



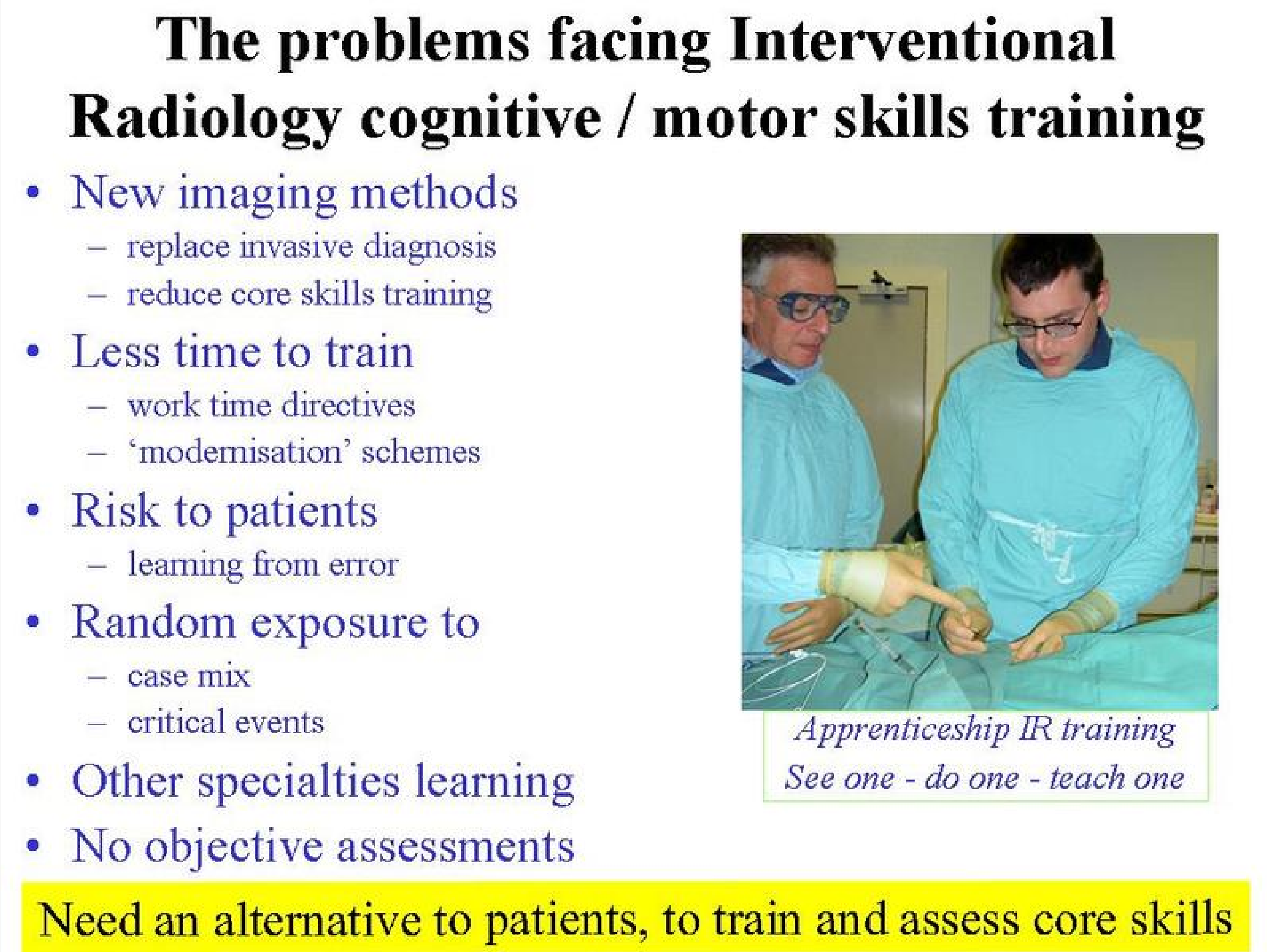
This two stage simulation lacks face validity. Considerable development work is ongoing to devlop this into a practicable simulation for training purposes.

Applications of Computer Based Simulation

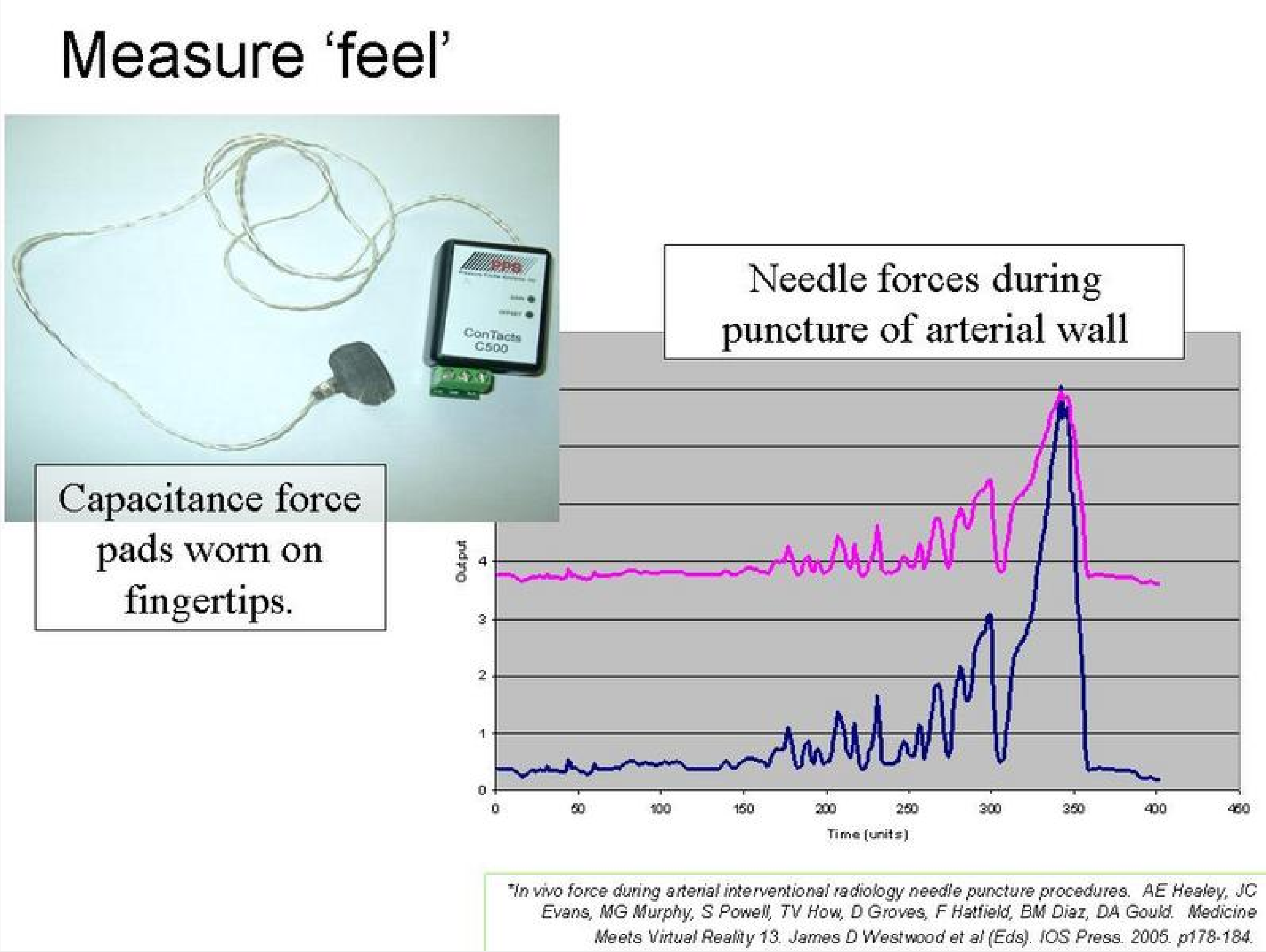


Only Computer Games are used for pure entertainment. The picture shows use of Second Life for a conference setting. The figures are 'avatars' of delegates at a conference conducted in the virtual world.

Apprenticeship training: the drawbacks



Capacitance force sensor pads (PPS, Los Angeles)



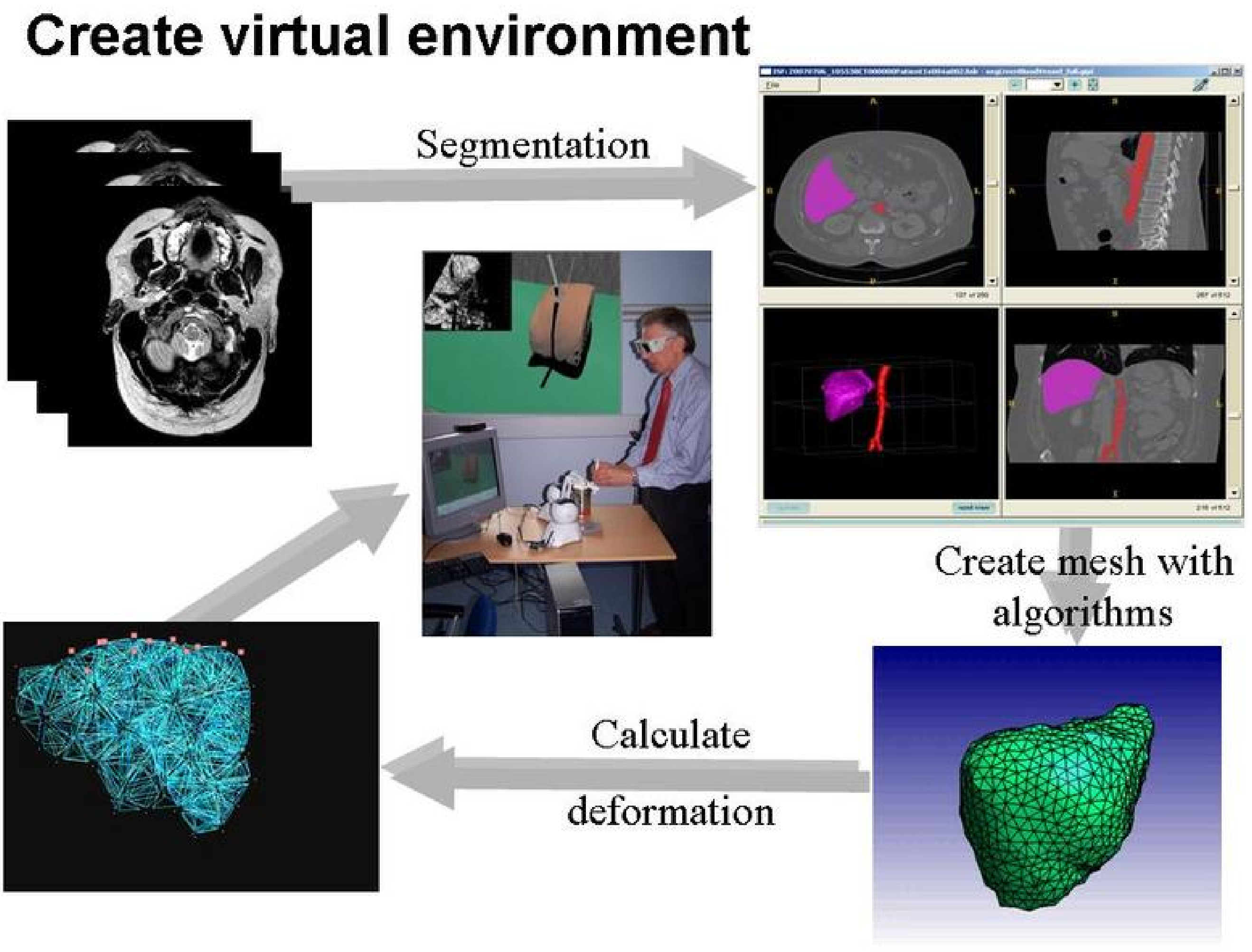
The pads are worn on operator's fingers. Data is collected into a laptop computer, recording forces generated during the procedure. Here the pads are positioned over a needle during arterial puncture.

Catheter / wire haptics devices

These devices convey the sense of feel of a wire and catheter, while mapping the operator's actions to the virtual catheter / wire.

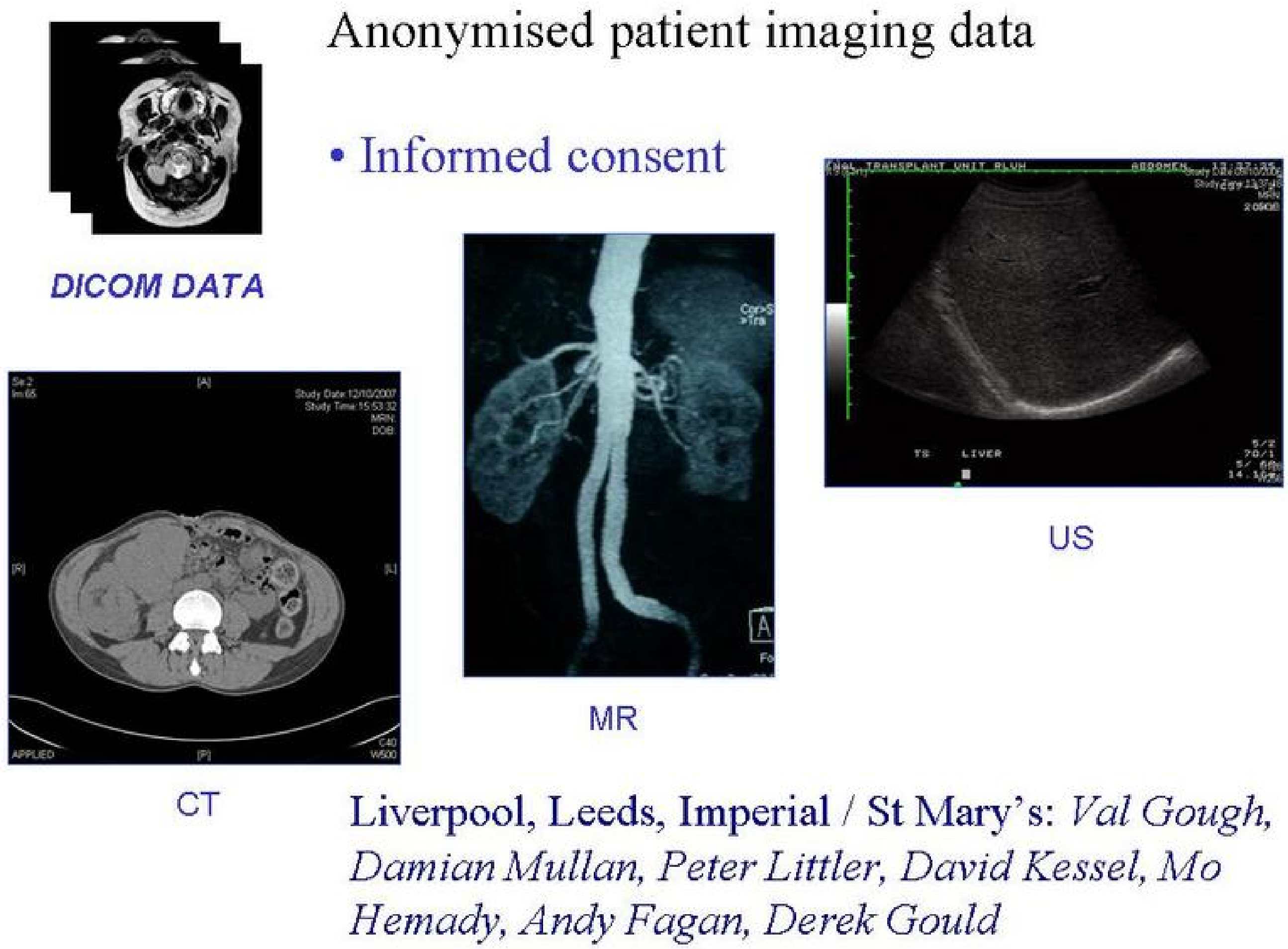
Come along to the Simulator Gallery at CIRSE 2008!

Create virtual environment



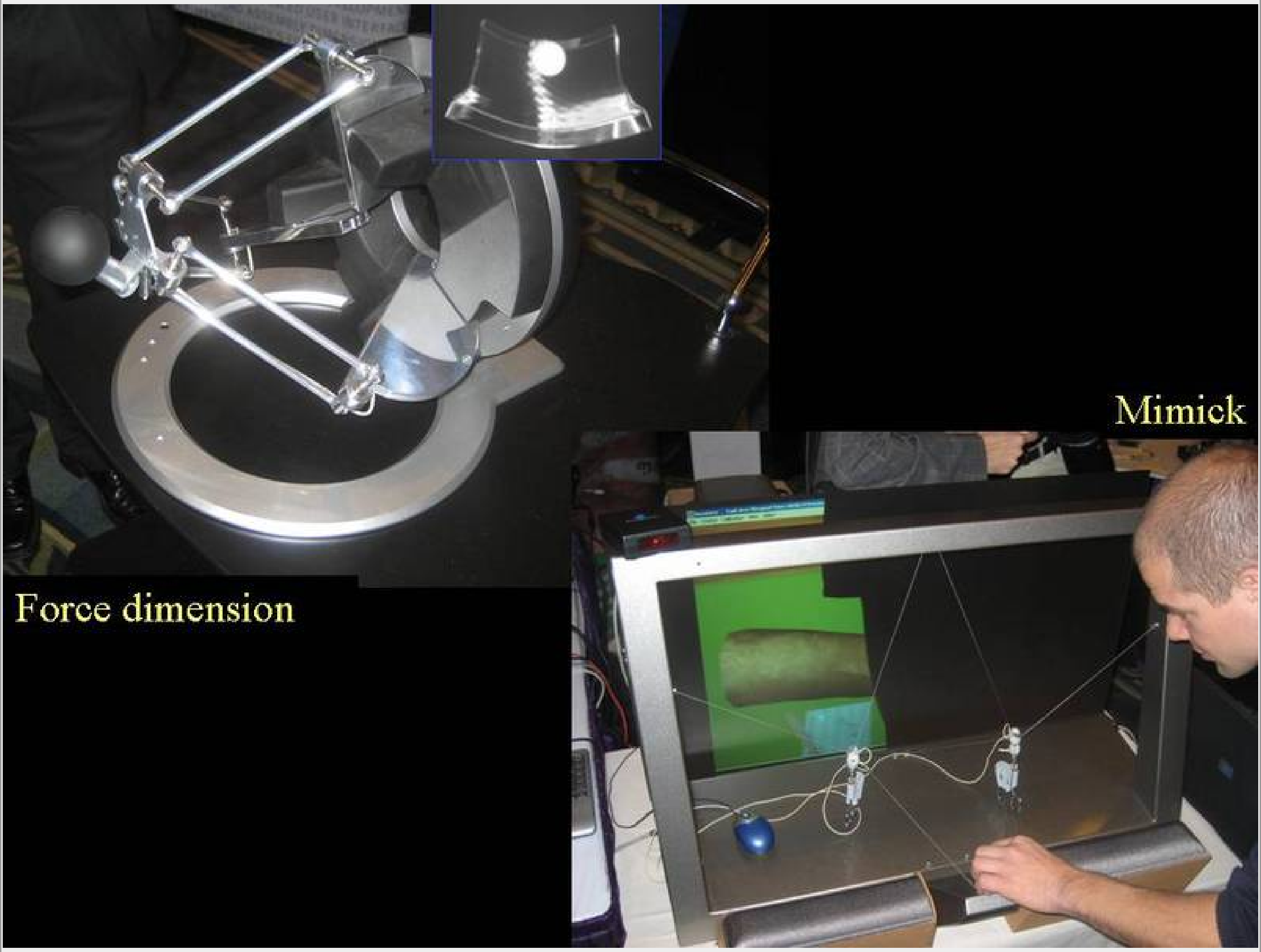
DICOM data is first segmented, then target anatomy is identified by segmentation (i.e. is labelled). A surface and volume mesh is created which contains nodes at intersections where mathematical formulae are located, to calculate deformations. Fidelity can be increased by increasing the number of intersections and therefore nodes, though this increases the computational load.

DICOM data as a basis for creating virtual environments.



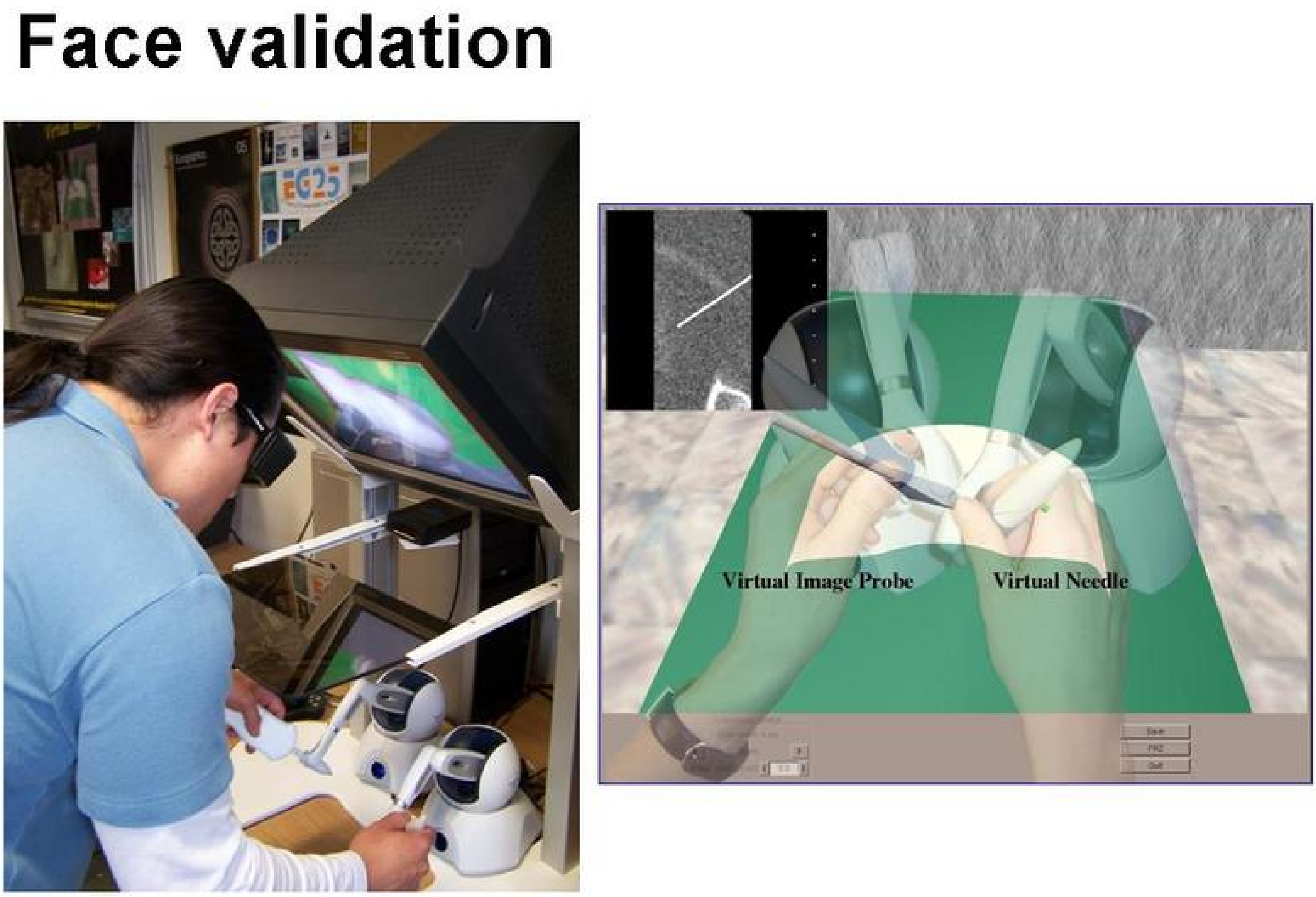
Use of patient imaging data is key to valid virtual environments, though requires patient consent, and anonymisation of data. Our imaging data sets are held on an ftp server at Bangor University Dept of Computer Science.

Haptics devices



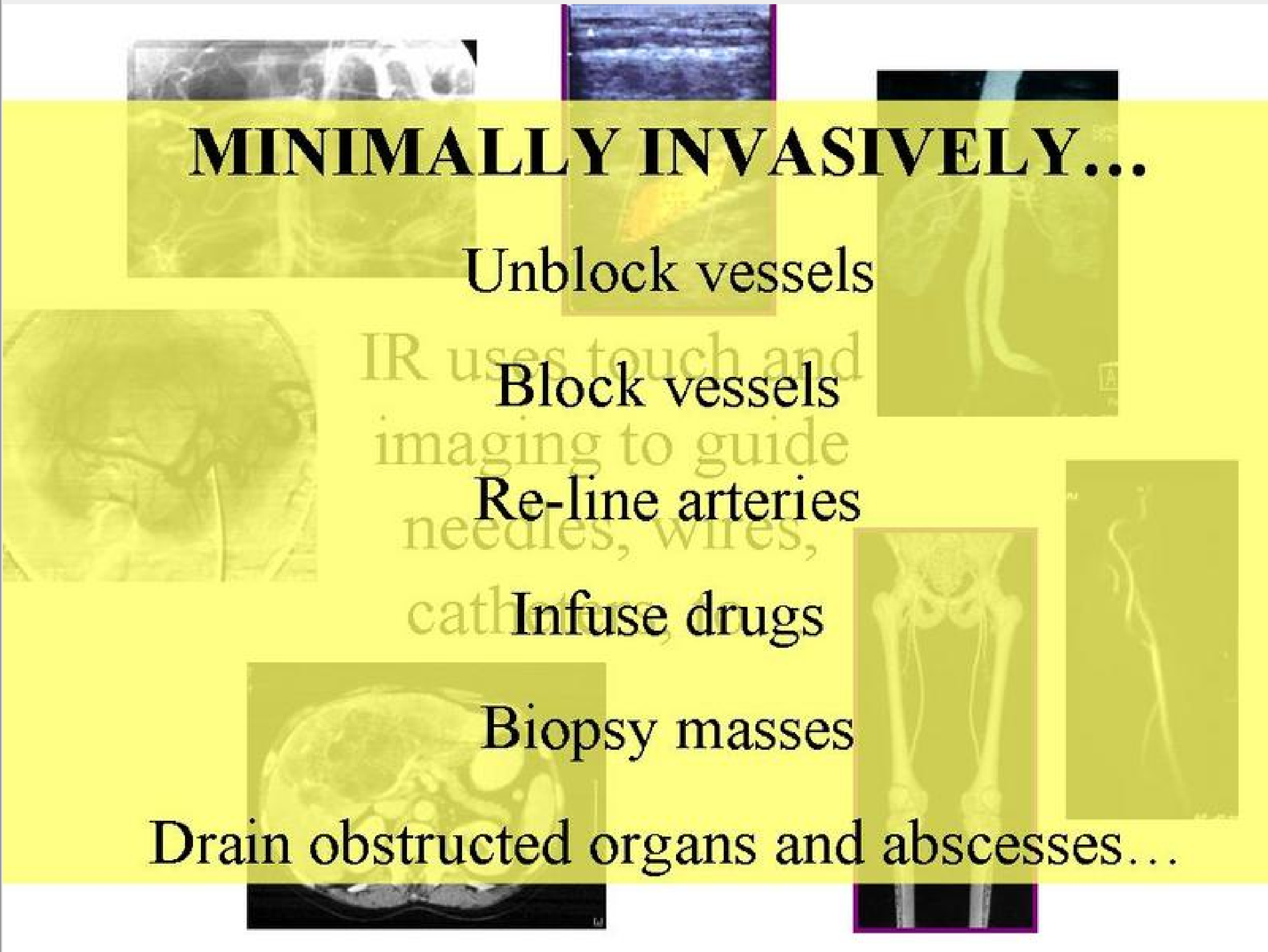
Haptics (always plural) means touch. The two devices illustarted use different mechanical methods to impart the 'feel' of a simulation to an operator. Force Dimension uses servo-driven, articulated arms. The Mimick device provides force sensation via a series of cables driven by motors.

Immersive environment for needle puncture simulation: 3D-IW by SenseGraphics

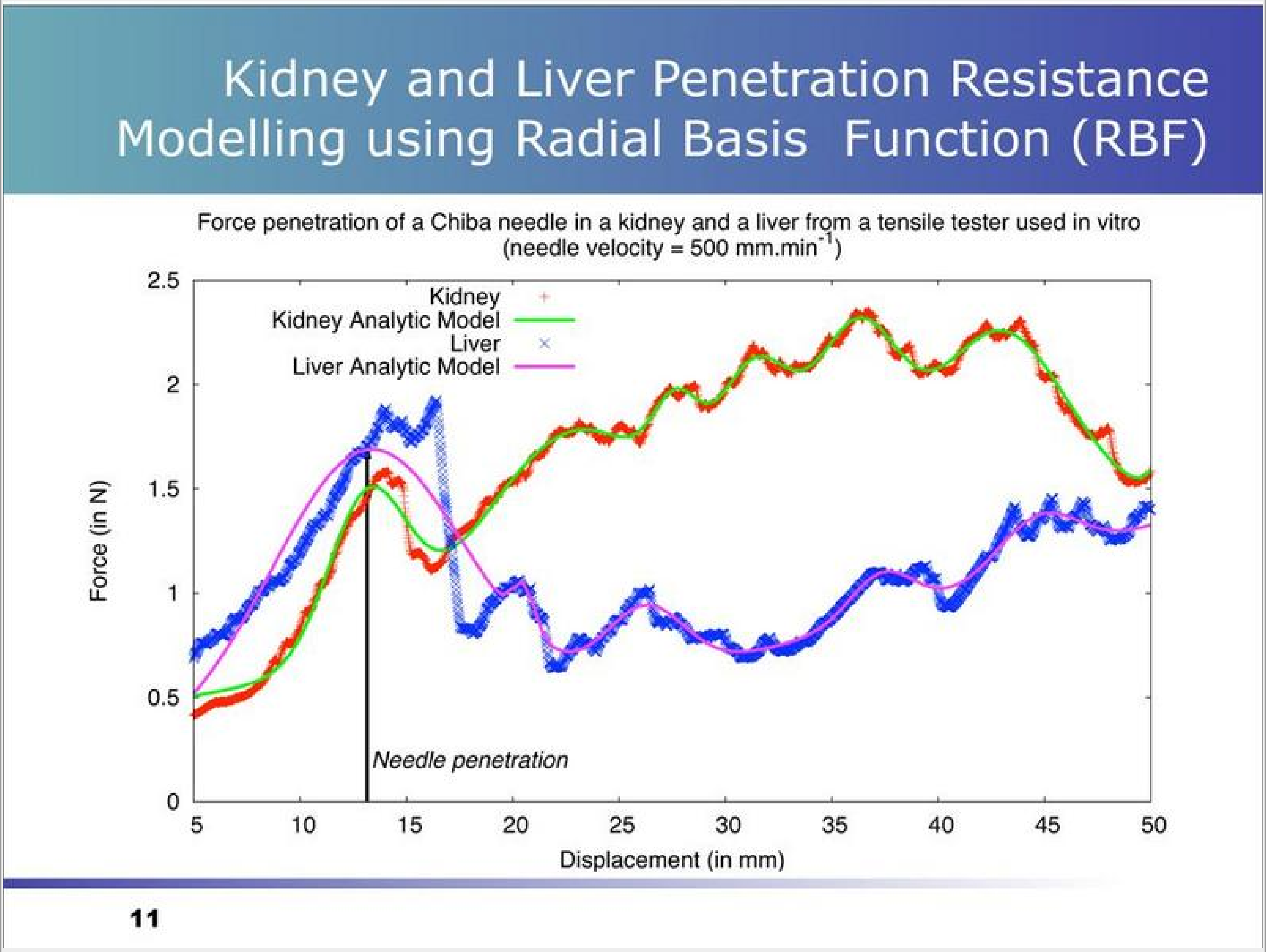


Here the operator's hands can be partially seen through the half silvered mirror which reflects the computer screen image. The hands are co-located with the instruments of the virtual world, while actually holding the haptic devices.

Interventional radiology uses imaging to guide minally invasive procedures



Kidney and liver penetration resistance modelling

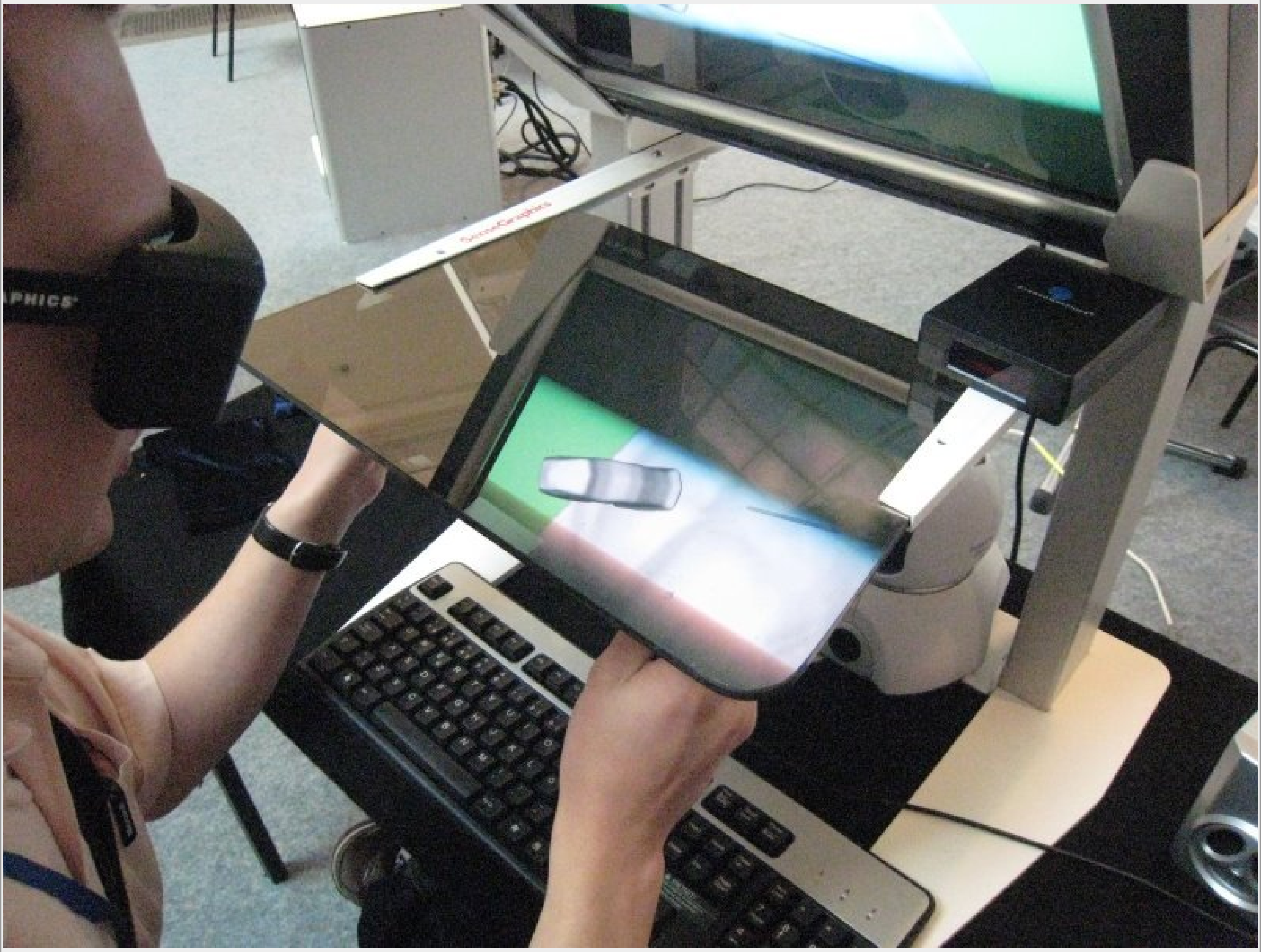


These force data provide more realistic feel to an operator when incorporated into the simulation.

Mediseus Epidural Simulation, MedicVision

This epidural simulation is notable for faithful replication of the characteristic tactile sensations encountered during performance of an epidural needle placement.

Needle puncture simulation with 3D viewing



This iteration of the simulation uses the 3D-IW (SenseGraphics, Färögatan, Sweden). The computer screen reflection is seen by the operator, and overlays the operator's hand, which are 'immersed' in the virtual environment.

Part of a task analysis document.

Task analysis: identify critical steps that require metrics

11. Puncturing artery

11.1. Position vascular access needle on incision site – between 2 fingers pressing down (see step 1.11), Bevel uppermost (see holding a vascular needle algorithm)

11.2. Insert needle through the nick in the skin at a 45 degree angle towards artery (with the orifice on the bevel of the needle pointing upwards and forwards so the wire can exit easily)

11.3. Feel the artery pulsation using non needle holding hand and align the needle trajectory with the artery

11.4. Advance the needle towards the artery.

11.5. Is there any indication from patient that more local anaesthetic is needed?

Yes (insert more local through arterial puncture needle and go to step 11.6)

No (continue to step 11.6)

11.6. Feel for the artery pulsating through the needle. Can you feel pulsation?

Yes (indicates near artery, go to step 11.7)

No (reposition needle and repeat step 11.6)

11.7 Puncture artery with either:

A sharp stab

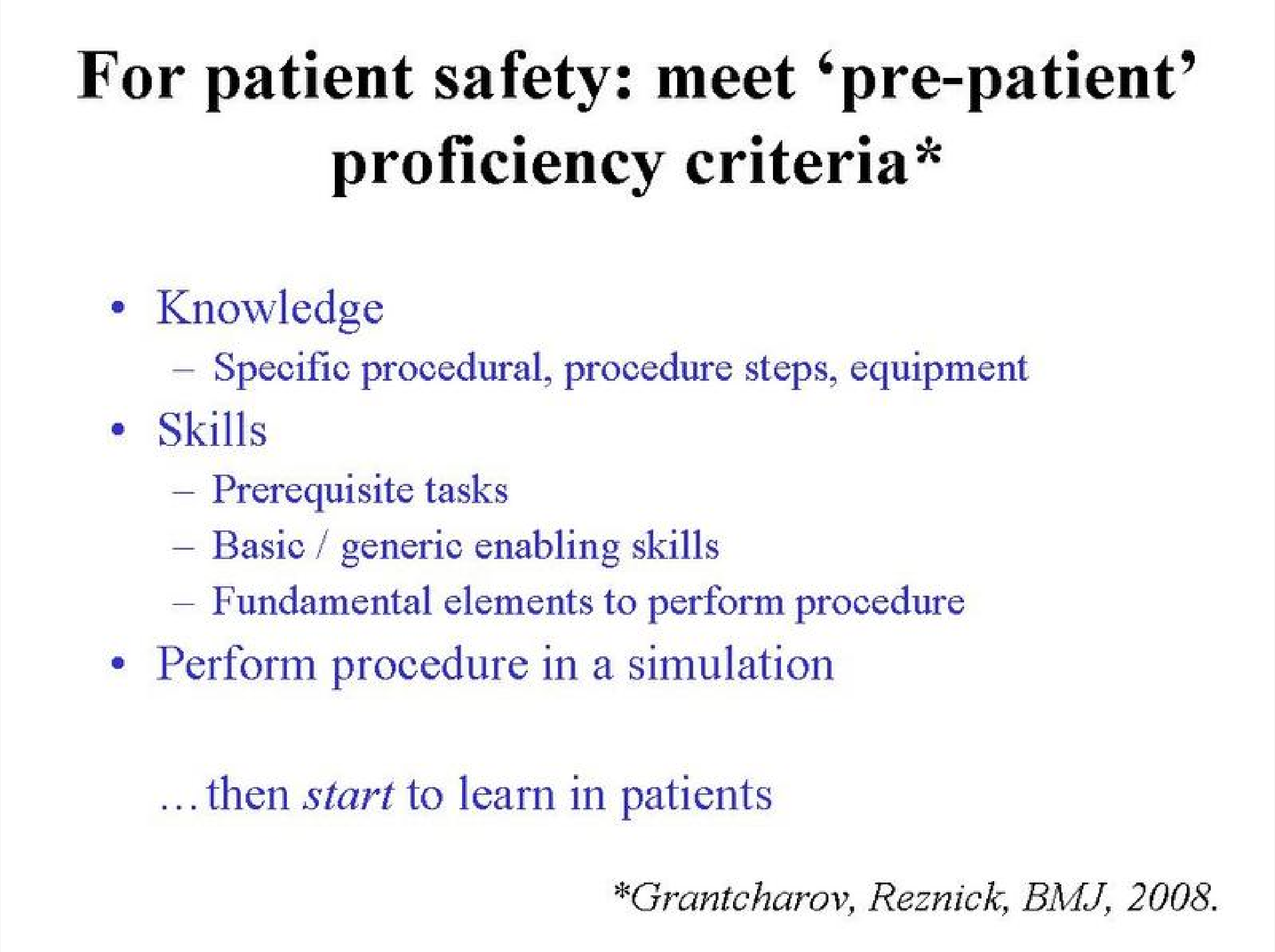
Gently increase pressure

11.8 Immediately but gently decrease angle between needle and patient

http://www.craive.org.uk/

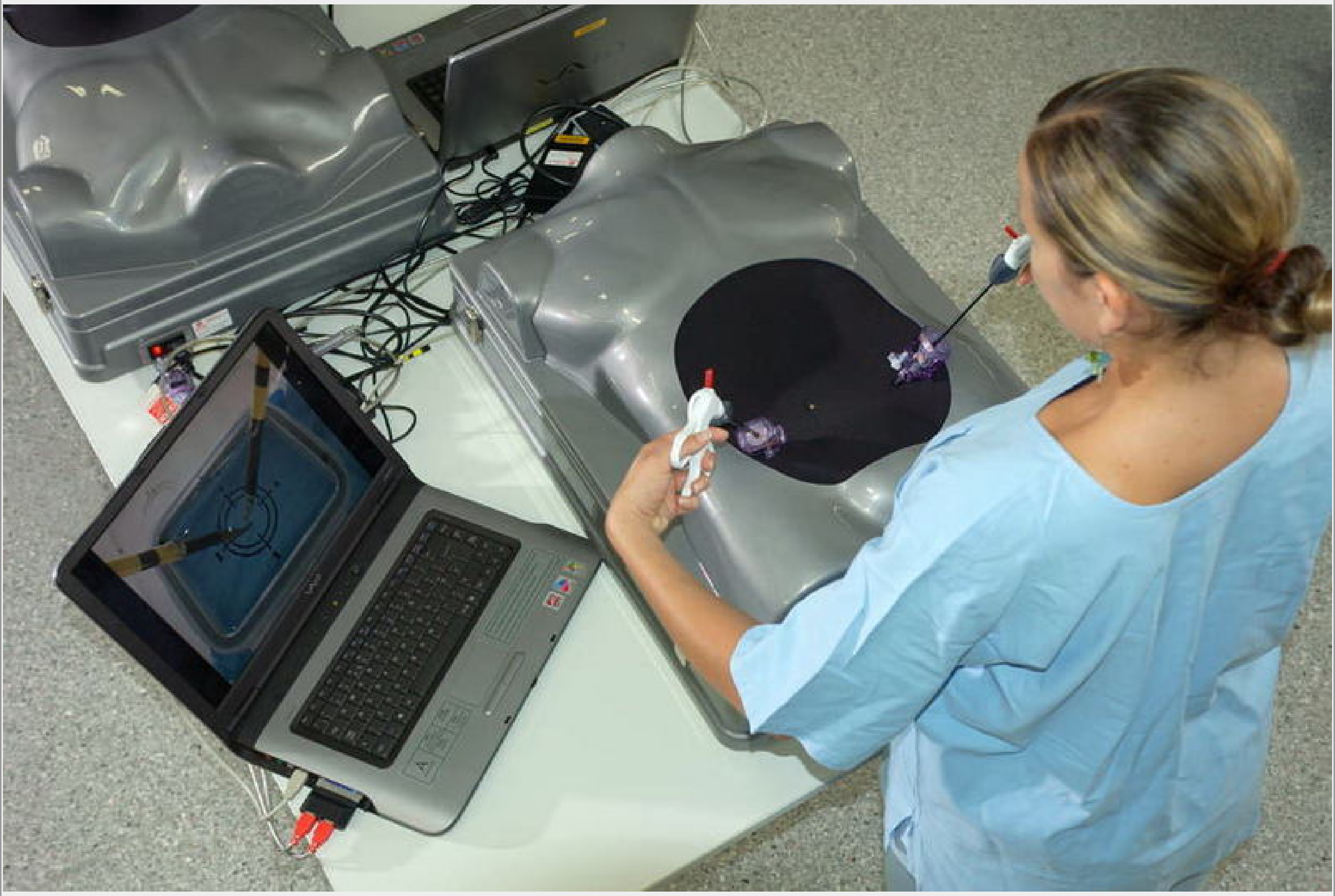
This analysis of arterial puncture shows just a part of the procedure. The procedure steps are identified in a hierarchical format and key, critical steps that require measurements to be applied (metrics) for assessments, are highlighted in green. The website (www.craive.org.uk) shows a number of analyses in full: these are in a constant state of evolution.

Pre-patient training.



Pre-patient training has been suggested as a method of resducing the risk of a novice's first exposure to patients.

Promis Simulator from Haptica in a skills centre setting



This is an augmented surgical simulator which allows one or more users to practice using real instruments held in a `normal' position with normal degrees of freedom: they operate on a manikin and use a laptop computer as a stacking unit view. Tasks may be physical or virtual (or a combination of both).

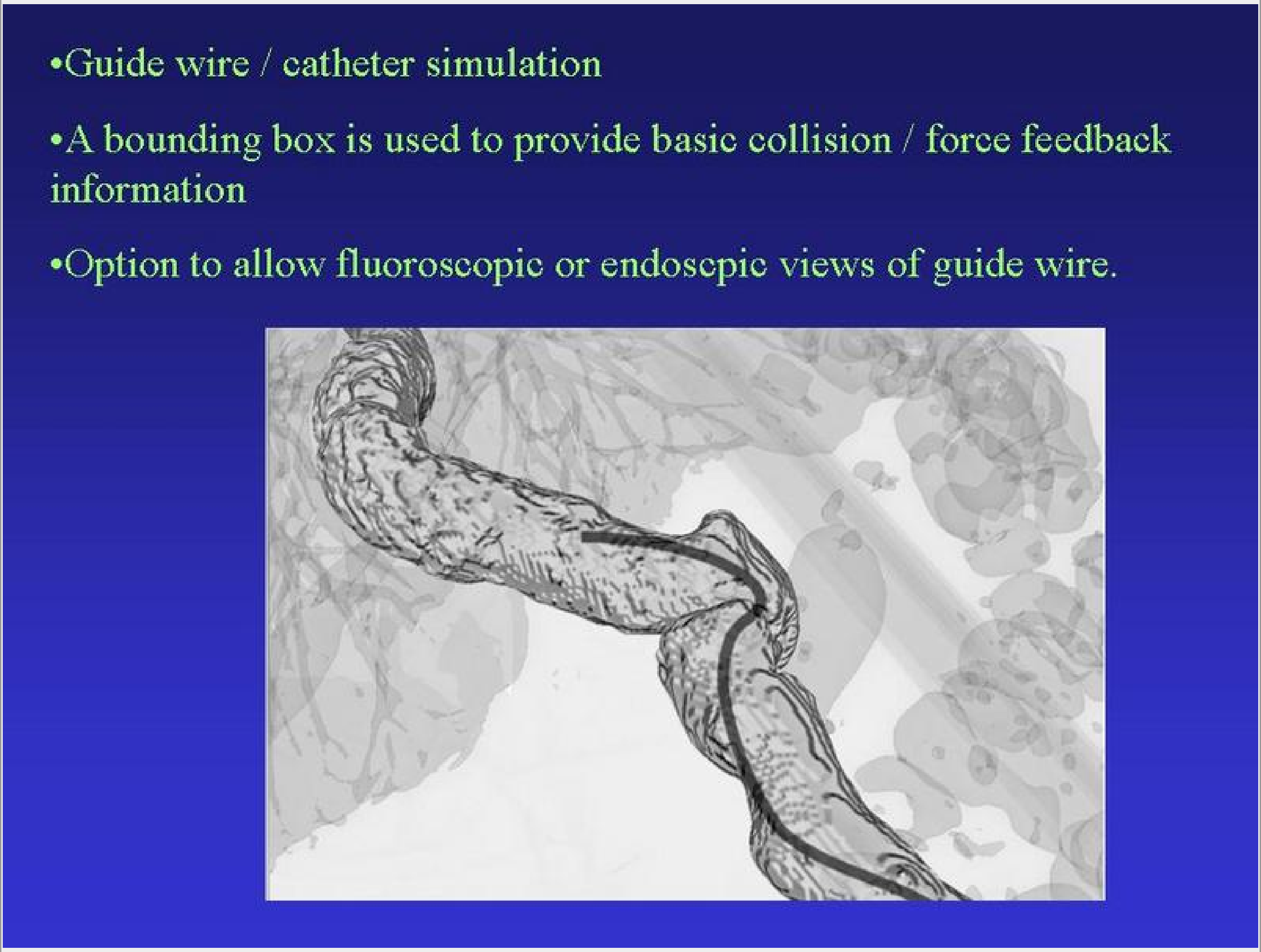
Simulation

Simulation: create a model to make predictions

- Computer based simulations use a virtual environment informed by algorithms to
  - Train to meet virtual / real world challenges
  - Provide assessments of operator performance
  - Work within a virtual environment, e.g. conferencing
  - Play a game (competitive)
  - Eliminate phobias
  - Design: buildings, cars, artefacts…

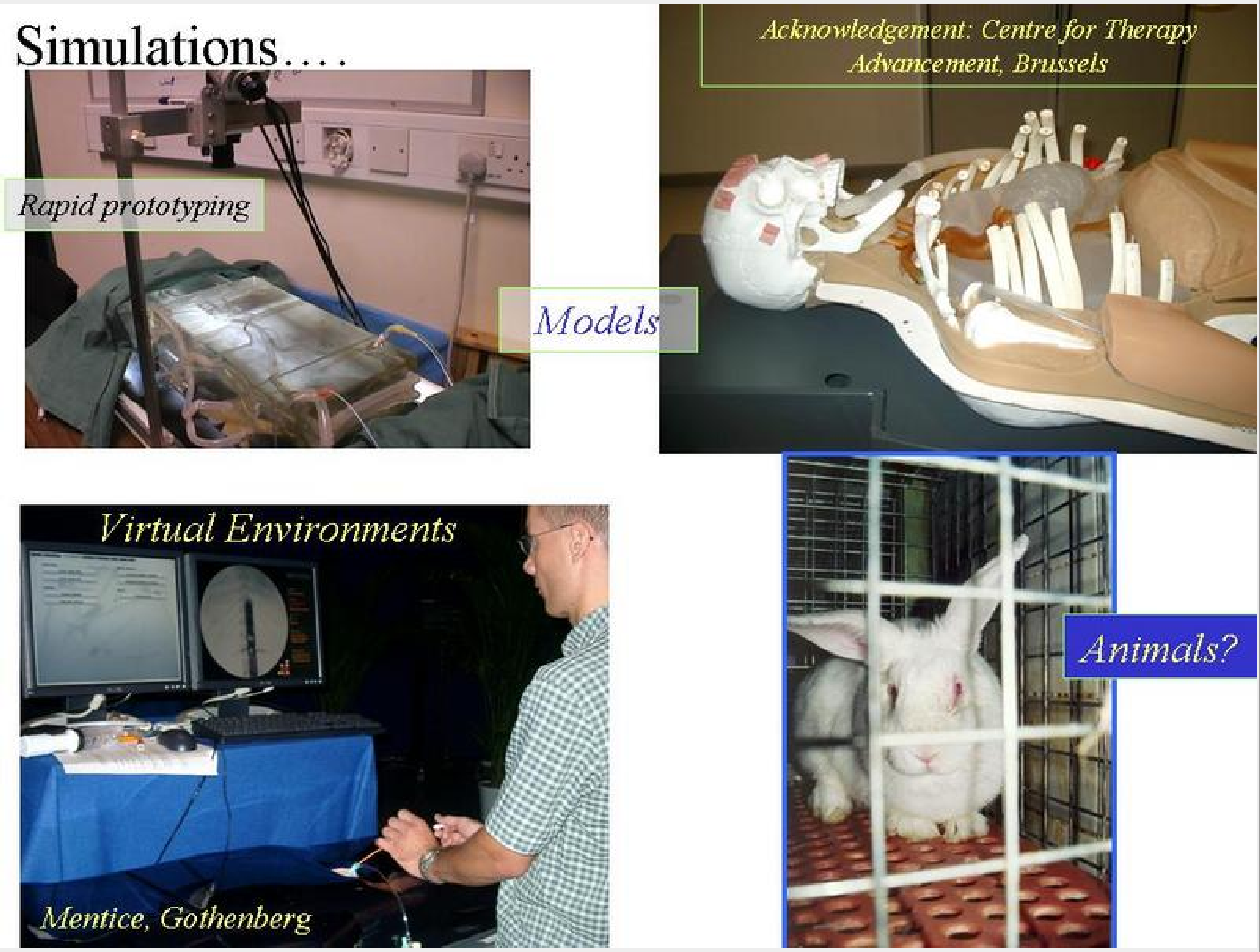
Simulations fulfil a range of applications, from games, including the serious games inmitiative, to high fidelity medical and aviation simulations.

Simulation of wire / catheter



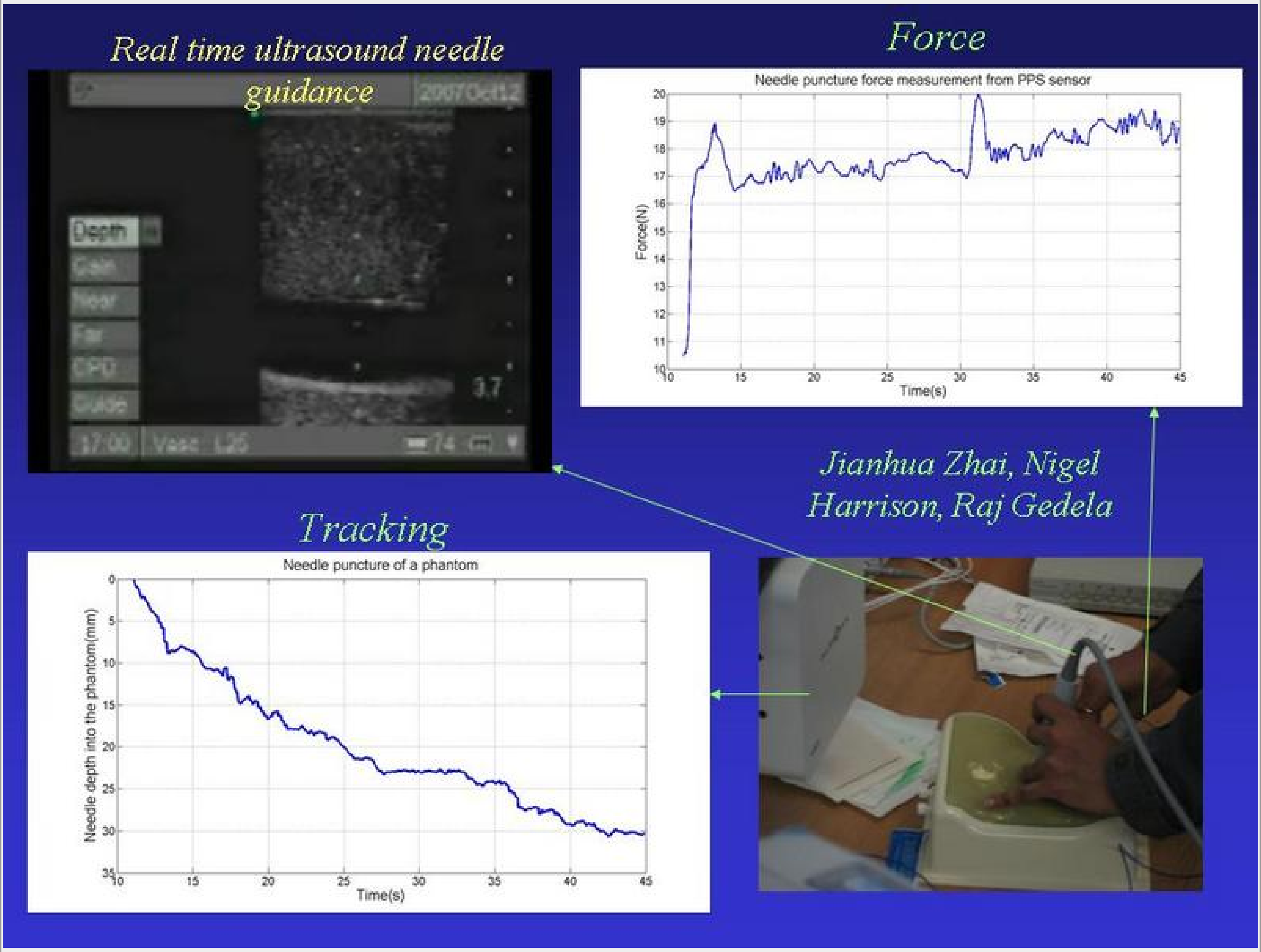
The operator's actions are mapped to a virtual wire / catheter, which is navigated through the virtual vascular tree.

Simulations for training



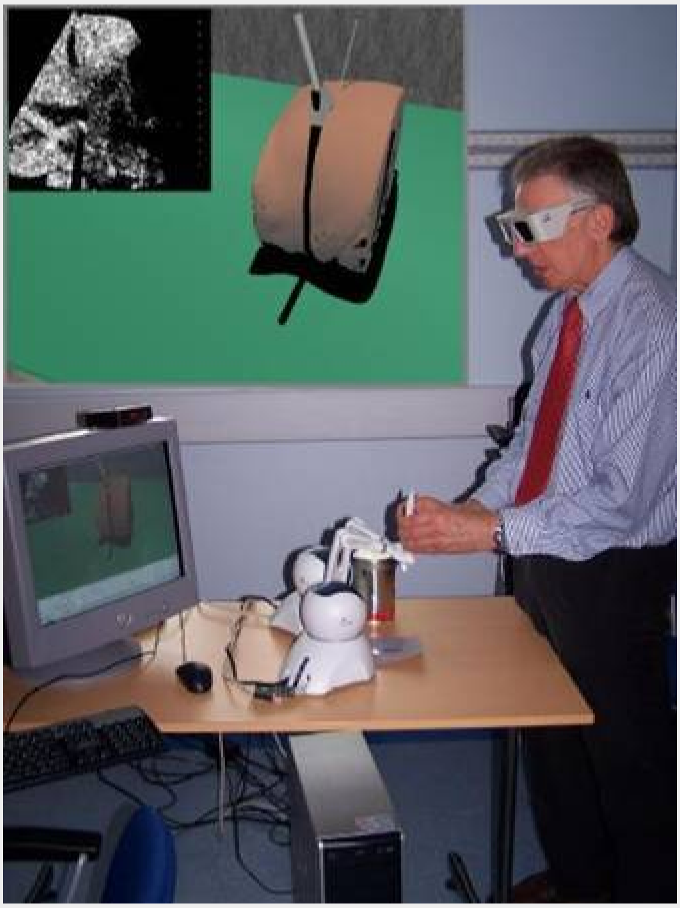
Fixed models are expensive, animals are expensive to maintain and use for training, and there are ethical issues, though they provide suitable content to mirror real world fidelity for physiology. Animals lack pathology though, and anatomy is dissimilar to human anatomy. Computer based simulations are an option, though are in an early state of development....

Tracking during force data collection



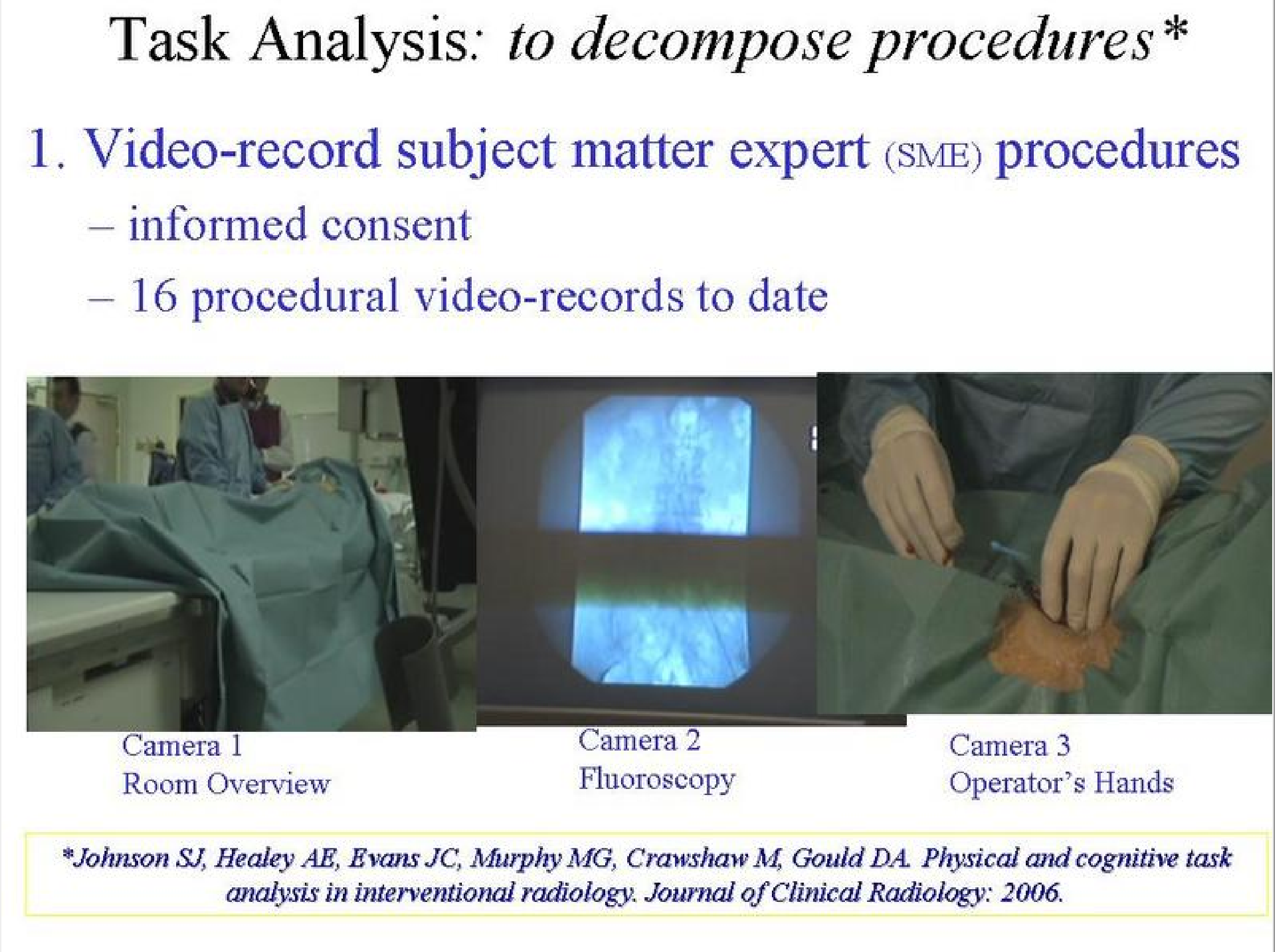
Magnetic tracking (Aurora, NDI, Toronto) is used to determine needle velocities. This allows force vectors to be derived for more accurate representation of tactile feedback.

Ultrasound simulation using a laptop computer



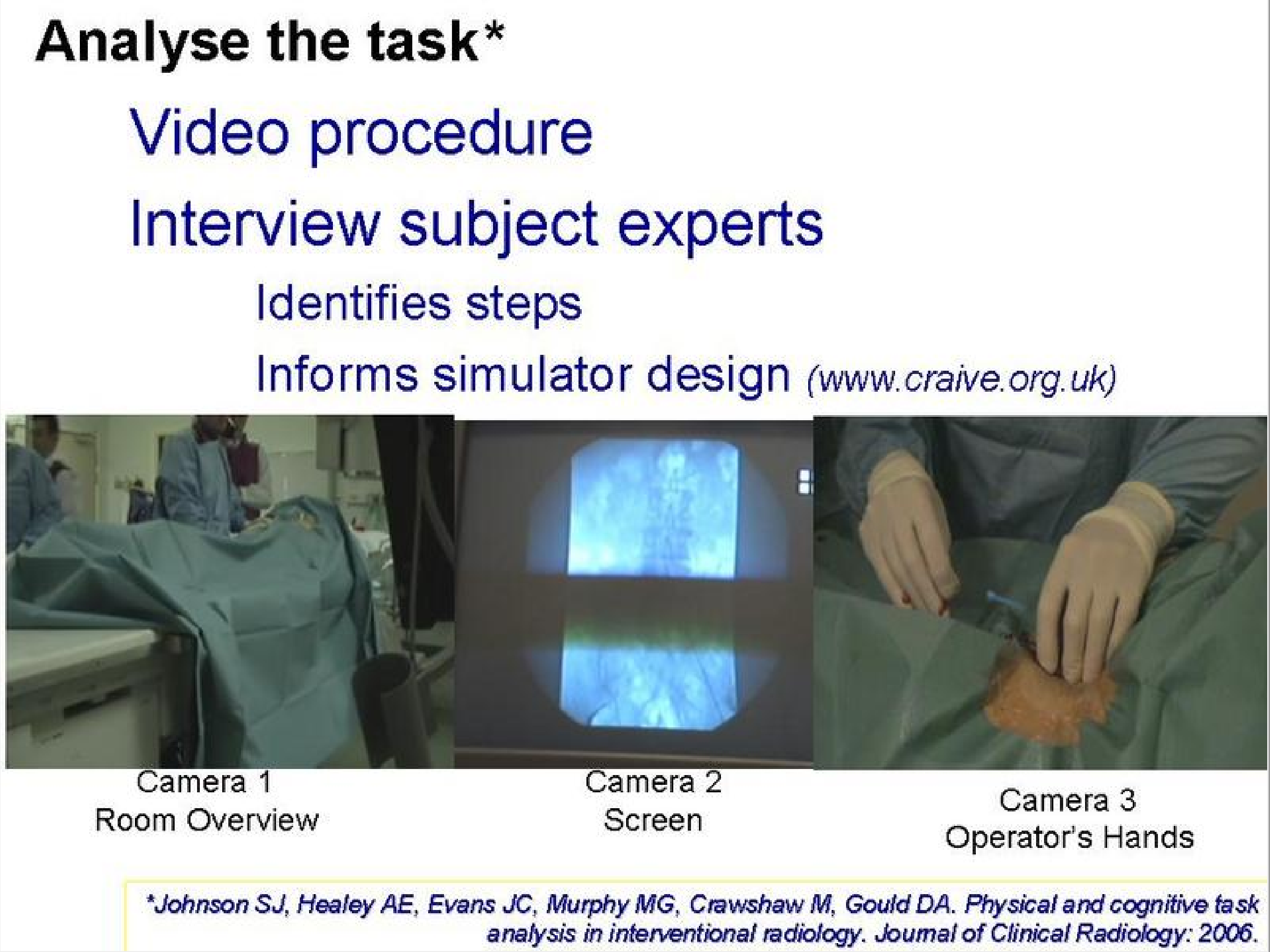
This shows the interim development of the CRaIVE ultrasound guidance simulation: see later.

Video-recording procedures



Procedures are performed by subject experts recommended by Societies. Thre cameras are used to record the whole room scene, the operator's handes, and the fluoro / ultrasound screen.

Videorecording procedures



Procedures are performed by subject experts recommended by Societies. Three cameras are used to record the whole room scene, the operator's handes, and the fluoro / ultrasound screen. The video is used as a prompt during interviews of subject experts to break down procedure tasks.

Wiki format of task analysis

Annotated task analysis (web based): to inform simulator design

	Task Analysis	*Realisation*	*Comments*
			seem too complex.
14.2.	*Insert needle through the nick in the skin at a 45 degree angle towards artery (with the orifice on the bevel of the needle pointing upwards and forwards so the wire can exit easily)*	*Trainee pushes needle phantom. Phantom provides 3DOF haptics. Trainee feels no torque on needle hub.*	
14.3.	*Feel the artery pulsation using non needle holding hand and align the needle trajectory with the artery*	*Trainee feels artery pulsation on mannequin (via haptic pulse device) using non needle holding hand and aligns the needle trajectory with the artery.*	
14.4.	*Advance the needle towards the artery.*	*Trainee advances the needle phantom towards the artery. The part of the needle inside the mannequin is entirely virtual.*	
14.5.	*Is there any indication from patient that more local anaesthetic is needed?* ***Q**. What are the indications to be observed?* ***A**. Patient complains of pain.*	*Not realised.*	*Patient voice activated complaining pain could be included in later vers of simulator.*
	***Yes** (inject more local through arterial puncture needle and go to step 14.6)*	*Not realised.*	
	***No** (continue to step 14.6)*	*D (decision point)*	
14.6.	*Feel for the artery pulsating through the needle. Can you feel pulsation?* ***Q**. What are the range and profile of forces felt?* *A. as 10.3*	*The phantom Omni provides this haptic feedback.*	*This is patient specific.* *I can't say I'm aware of the artery pulsating through the needle. I'm guided by the other hand*
	***Yes** (indicates near artery, go to step 14.7)*	*D*	
	***No** (reposition needle and repeat step 14.6)*	*Trainee moves needle.*	
14.7.	*Puncture artery with either;*	*NA*	

http://www.craive.org.uk/

In this format, computer scientists and subject experts can input the process of relaisation of the simulation, deriving this from the task analysis.