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# Physics-based virtual environment for training core skills in vascular interventional radiological procedures

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**Abstract**

Recent years have seen a significant increase in the use of Interventional Radiology (IR) as an alternative to open surgery. A large number of IR procedures commences with needle puncture of a vessel to insert guidewires and catheters: these clinical skills are acquired by all radiologists during training on patients, associated with some discomfort and occasionally, complications. While some visual skills can be acquired using models such as the ones used in surgery, these have limitations for IR which relies heavily on a sense of touch. Both patients and trainees would benefit from a virtual environment (VE) conveying touch sensation to realistically mimic procedures. The authors are developing a high fidelity VE providing a validated alternative to the traditional apprenticeship model used for teaching the core skills. The current version of the CR*a*IVE simulator combines home made software, haptic devices and commercial equipments.

## 1 Introduction

Across all disease areas, there is a remorseless shift from open surgery to management by Interventional Radiology (IR). IR is minimal access surgery using imaging (e.g. X-ray fluoroscopy, ultrasound) to guide the manipulation of needles, wires and catheters in vascular and organ systems. IR vascular procedures commence with the Seldinger technique: a needle is inserted into an artery or vein, usually under local anaesthesia, and guided by touch (e.g. palpation of a pulse) or ultrasound. A guidewire is then manipulated through the needle and into and along the vessel, where the operator's skill and 'feel' are key to reducing the risk to patients of improper technique, e.g. vessel obstruction or perforation. The wire then acts as a conduit for a catheter, which may be advanced into more distant vessels for angiography (injection of x-ray-opaque dye or contrast medium) or for therapeutic procedures such as balloon angioplasty. An apprenticeship in patients, with expert supervision, has served to train all radiologists in these core skills, commencing with straightforward, diagnostic angiography, then progressing through more complex cases. The need for supervision, however, increases procedure time and cost [2], while remain the inevitable added risks and discomfort for patients of inexpert manipulations. In addition, pressures to improve throughput, together with working time restrictions, are increasing the difficulty for trainees to acquire experience in a time efficient manner [4, 1]. New methods are therefore urgently needed to address the pressing need to train and assess IR skills to a level where it becomes safe to commence practice in patients. CR*a*IVE is a consortium consisting of clinicians, physicists, computer scientists, clinical engineers and psychologists with the aim of implementing and validating sophisticated VEs designed for use in the training of radiological interventional procedures. This paper describes the current version of a patient specific Seldinger technique simulator being developed as a collaborative project involving UK hospitals and Universities: Royal Liverpool and

St James's University (Leeds) Hospitals, Manchester Royal Infirmary, Universities of Manchester, Leeds, Hull, Bangor Liverpool and Imperial College London.

## 2 Related Work

While a number of virtual reality products simulating IR catheterisation procedures (Mentice, Immersion Medical, Medical Simulation Corporation, Simbionix) and needle puncture (Immersion Medical, Simbionix) exists, these are of varying functionalities and none combines needle puncture with catheter insertion for vascular access. The Immersion Cathsim intravenous puncture haptic device permits venous guidewire, but not catheter, introduction (`www.immersion.com`). Despite some current commercial simulations (e.g. Mentice, Simbionix) using physics based models, there is a lack of accurate 'feel' in existing systems [3], and none uses pulse palpation for needle guidance (which is important for clinical success), neither combines needle and catheter introduction, nor directly accepts patient specific data selected by the end user. In addition, while improved proficiency in patients has been demonstrated for simulations of anaesthesia, colonoscopy and laparocopy (e.g. the Mentice MIST-VR) to date, none has been clinically validated for IR training and assessment. In the university sector, various authors have described catheterisation simulation [5] though without haptics or needle puncture. Others describe simulated catheter insertion in patient specific datasets [7] but without arterial palpation, ultrasound guidance or use of haptics based on direct measurement of procedural instrument-tissue forces. Needle puncture simulation has been described in liver biopsy, lumbar puncture and using ultrasound guidance [6] but without using empirical force values. Thus at present, there is no adequate, validated VE model for training interventional radiologists in vascular needle access for catheterisation, guided by touch and imaging.

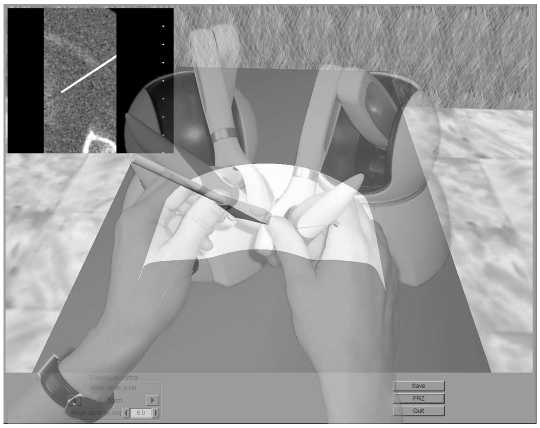
## 3 Tools and Methods

The aim of our work is the development and validation of a physics-based VE for training of vascular IR procedures, with an emphasis on the core skills required to perform the Seldinger technique. Key characteristics of our approach include:

- Systematic task analyses to guide and inform simulator development.
- Generation of variable virtual anatomy from patient specific data sets supported via a direct facility to load DICOM data and semi-automatically produce a range of 3D geometry of vascular and surrounding tissue structures.
- Use of unobtrusive sensors during palpation, needle puncture, guidewire and catheter insertion into blood vessels in patients to determine and localise forces.
- Combining suitable deformation models incorporating tissue resistance, tissue and vessel deformation, pathology and physiological pulsation to simulate needle puncture, and introduction of a guidewire and a catheter into a blood vessel.
- Use of a novel haptic pulse device and US to guide needle puncture by palpation.
- Guidewire and catheter manipulation using fluoroscopy, simulated from CT data.

## 4 Results

Physical and cognitive task analyses of the procedures to be simulated have been carried out and provide an invaluable resource. Each sub task is broken down into fine detail and realised in the described VE. To simulate a core skill such as the Seldinger Technique, the CR*a*IVE simulator has two stations. The first station (Figure 1(a)) uses a Phantom Omni haptic device to represent the




(a) Station 1 - Local Anaesthetic and Arterial Puncture.

(b) VSP Haptic Device used in Station 2.

***Figure 1:*** CR*a*IVE Seldinger technique simulator.

needle used for injecting local anaesthetic, and the vascular access needle. A virtual ultrasound transducer is implemented using a second Omni device to guide the needle puncture. The second station deals with the guidewire and catheter manipulation. A purpose built haptics device from Mentice, the Vascular Simulation Platform (VSP), provides the necessary hardware, Figure 1(b).

# 5 Conclusions

The current CR*a*IVE simulator is a starting point. Many improvements and adjustments will be incorporated later. We are identifying quantitative measures of learning and transfer of skill from the task analyses, and validating effectiveness for training. Suggestions will be made for inclusion in curricula and criteria for certification.

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