Virtual Needle Simulation with Haptics for Regional Anaesthesia

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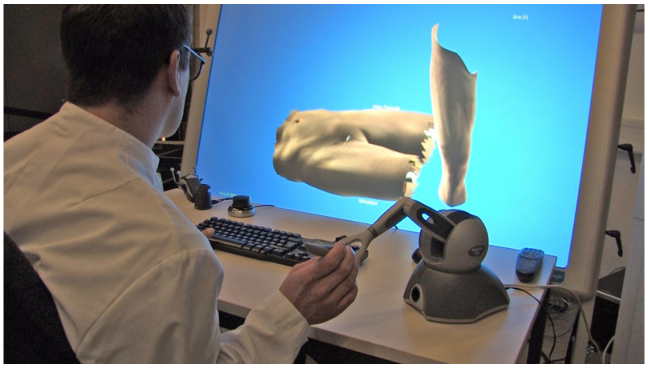

Figure 1: Overview of the regional anaesthesia simulation prototype with an immersive virtual reality system.

ABSTRACT

This paper reports about an ongoing research project, called RASim. The goal of this project is to develop a virtual reality-based training tool for regional anaesthesia. A production pipeline to create patient-specific datasets has been established. A prototype of the simulator has been implemented on a virtual reality-platform and was evaluated in a first study. The current research and development is focused on soft-tissue simulation and haptics to improve the interaction. Furthermore, a bi-manual interaction scheme to combine palpation and virtual needle guidance is introduced as conceptual work and will be evaluated soon.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; J.3 [Computer Applications]: Life and Medical Sciences

1 INTRODUCTION

Needle simulation is an important topic and has a broad field of applications in clinical procedures, e.g., biopsies, injections, neurosurgery, brachytherapy cancer treatment and regional anaesthesia. We focus on regional anaesthesia (RA) because training opportunities are limited [7, 2] and there is a lack of available virtual reality-based (VR) RA simulators. RA requires profound theoretical knowledge and repeated performance to gain sufficient manual skills for successful accomplishment of such procedures [10]. Although there is widespread utilization of simulators to learn and improve medical skills in general and sophisticated full-scale simulators for general anaesthesia, the use of such mannequins for RA training is limited by patient variance, inaccurate representation of biological tissue, and physical wear from repeated use. In an interdisciplinary approach, we therefore launched the Regional Anaesthesia Simulation (RASim) project (http://www.rasim.info/).

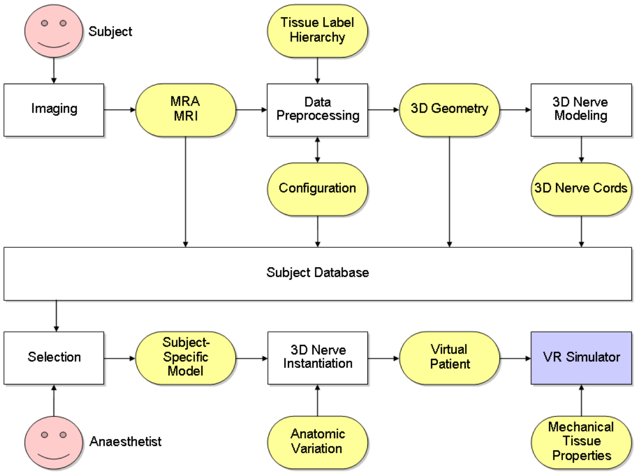

Figure 2: This production pipeline (virtual patient architecture) describes all the steps from a real patient/subject to the VR simulator [13].

2 PIPELINE FOR SUBJECT-SPECIFIC DATASETS

To provide the simulator with several subject-specific data configurations and to support different training scenarios a production pipeline has been established (Fig. 2). A database is built with inputs based on non-invasive magnetic resonance imaging (MRI) and customized magnetic resonance angiography (MRA). For *imaging* MR scanner protocols have been adjusted together with radiologists [6] to improve the contrast of morphology in MRI scans and to visualize blood vessels in MRA without contrast agent. In a first step five subjects have been scanned. Tissue types, that are relevant for the simulation (e.g., skin, fat, muscle, blood vessels and bones), are segmented in the *data processing* step. The Medical Imaging Interaction Toolkit (MITK) [5] has been used to add own modifications and optimizations for segmentation algorithms [11]. Ongoing work is focused on semi-automatization of this time-consuming step. Unfortunately, cross-sections of nerve cords only occur infrequently on MRI protocols and similar grey values of other tissue render segmentation attempts impossible. Therefore, for *3D nerve modeling* we have created a tool to construct spline-based virtual nerve cords interactively with control points in a three-dimensional environment [12]. The modeling tool could be also used to create parametrized representations of blood vessels. For now, we only use static blood vessels geometry extracted by the segmentation algorithms. To import datasets into the *VR simulator*, the physician

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Figure 3: Virtual palpation by sliding a virtual hand over the skin surface with visual display of underlying landmarks.

can choose a subject in a *selection* step. In the *3D nerve instantiation* the spatial configuration of the nerve cords can be (optionally) varied randomly in order to obtain a unique virtual patient for each training session. For this step, we have parametrized typically anatomical variations of nerve branches, e.g., different areas where a certain branching can occur.

3 SIMULATOR PROTOTYPE

The simulator utilizes the VR toolkit ViSTA [15] which allows easy deployment on either standard desktop systems or on various virtual reality hardware. To simulate needle interaction and electric impulse transmission, a novel approach based on electric distances has been developed [14]. A simulator prototype has been developed for the femoralis block in the inguinal region. More procedures in the same region, e.g., sciatic nerve block, and new regions will be added later.

The application starts in palpation mode. First, the user has to localize important anatomical landmarks that are subject-specific and thus can differ each time. To perform the palpation, a virtual hand (with an extended index finger as a "sensor") can be moved over the skin surface of the virtual patient (Fig. 3) with a PHANTOM Omni Haptic Device. As soon as a particular puncture site has been chosen by the trainee, the interaction mode can be switched to needle interaction. Then, the virtual hand is replaced by a virtual needle, which is coupled to the input device and can be moved and rotated freely outside the virtual patient (Fig. 1). Once the skin surface has been penetrated, the movement is currently restricted to the injection direction (i.e., along the axis of the needle shaft). However, it is very common for medical staff to change angular positions of the needle after skin penetration in order to reach a correct placement inside the tissue. Therefore, we are working on a more realistic solution, which will depend on the penetration depth and tissue stiffness. At any time during the training procedure a virtual aspiration can be triggered by the trainee, to check whether the needle tip is inside a blood vessel. The simulation of the nerve stimulation is automatically active when the needle is inside the virtual patient. Hence, if a virtual nerve cord is within emission range of the needle tip, according muscular motor responses are displayed in real-time. The amplitude of the electric impulses can be controlled by a simple 2D-GUI. Usually, this parameter is initially set to 1 mA and then gradually being reduced to narrow down the search volume. In case of missing motor feedback, either the needle can be relocated or the user can switch back to palpation mode to search for a better insertion site. Once the trainee has reached the desired target area, the needle can be fixed and individual anatomical layers can be turned transparent to offer a review opportunity to gain better insight. The whole procedure is recorded by an event logger and thus the interactions can be replayed for further assessment or analysis.

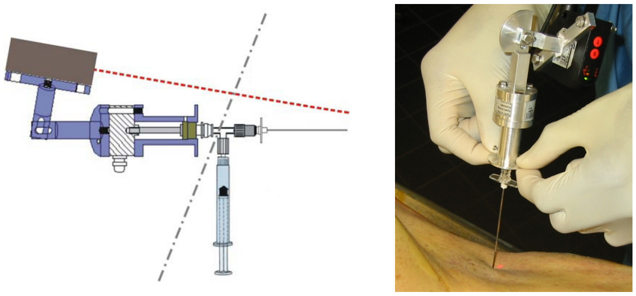

Figure 4: Measuring device for force/distance-recording attached to a surgical needle: schematic view (left) and prototype used on cadaver (right). The red line depicts a laser beam for distance measurement and the grey dashed line indicates a sterile enclosure.

4 HAPTICS AND BI-MANUAL INTERACTION

In order to support haptics, first we want to measure the resistance forces encountered during real RA procedures. Therefore, a force-sensor and distance-measure are non-intrusively attached to a RA needle (Fig. 4). This special sterilized apparatus is currently under inspection at the local ethical review board. Early prototypes have been already tested on cadavers.

Soft-tissue deformations will be simulated with FEM algorithms provided by the Simulation Open Framework Architecture (SOFA) [1]. We are optimizing our segmented geometries from the subject-specific database (see Sec. 2) to create well-shaped tetrahedral volume meshes [9]. Several approaches to needle bending are currently being adapted and evaluated [3, 4].

Finally, we are currently working on a concept for bi-manual interaction to enable concurrent palpation and needle guidance. During a procedure the non-dominant hand can be used to deform or stretch the skin surface while the primary hand is used for the needle insertion. From a technical point of view this manipulation by the non-dominant hand does not differ from palpation. We want to use two haptical devices, one for the dominant hand to control the needle: here a pen-like devices does not need to be modified. For the non-dominant palpating hand, we will exchange the pen end-effector of the haptic device by a thimble. Furthermore, the simulation will be optimized to allow different kinds of deformation from both the virtual needle and virtual finger.

5 CONCLUSION

In this paper we have summarized the research results of our work on a RA simulator. The pipeline described in Section 2 has been used for five subjects so far. It is planned to extend the database with more cases and also work on other body regions. In Section 3 a prototype of the simulator has been summarized. A user study with ten residents and consultants has been conducted and provided further insight [13]. We are closely collaborating with experienced medical staff, to evaluate anatomical details of the data sets and also to have regular cognitive walkthroughs with experts. With Section 4 we have provided a glimpse at our current and ongoing work on haptics and a novel bi-manual interaction. Furthermore, we hope to adopt some of the data format in our database to the emerging MedX3D standard in the future [8].

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