Exploring the Simulation Requirements for Virtual Regional Anesthesia Training

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ABSTRACT

This paper presents an investigation of the simulation requirements for virtual regional anaesthesia training. To this end, we have developed a prototype human-computer interface designed to facilitate Virtual Reality (VR) augmented educational tactics for regional anaesthesia training. The proposed interface and semi-immersive system aim to complement the nerve blocking techniques methods. The system is designed to operate stereoscopically presenting anatomical information and enabling the user to explore the spatial relation of different human parts without any physical constraints. Opting for a sophisticated approach of interaction, the interface elements are based on the simplified visual representation of real objects, and can be operated through haptic devices and surround auditory cues. This paper discusses the challenges involved in the HCI design, introduces the visual components of the interface and presents a tentative plan of future work which involves the development of realistic haptic feedback and various regional anaesthesia training scenarios.

KEYWORDS

VR Interface, Regional Anaesthesia, Medical Visualisation, Anatomy, Medical Education, HCI.

1. INTRODUCTION

Contemporary technological advancements have enabled photorealistic depiction and simulation of a wide range of complex anatomical data for training and diagnostic purposes. To this end, previous studies have demonstrated that anatomy learning can be augmented by the use of high-resolution 3D models and intuitive human-computer interactions [1, 2,3,4].

This study investigates the use of virtual reality simulation for training purposes in peripheral regional anaesthesia techniques with a particular interest in Ultrasound Guided continuous interscalene block [5,6,7]. A major benefit of regional over general anaesthesia is that the first enables the patient to remain conscious during the operation, enabling the surgeon to communicate with the patient. Furthermore, regional anaesthesia reduces significantly the recovery time and any postoperative anaesthetic related complications. Hence the niche of regional anaesthesia has recently expanded considerably due to real-time imaging technology. In particular ultra-sound imaging has significantly supported regional anaesthesia by providing an aid to increase the accuracy of the block especially in surgical operations involving the upper and lower limbs.

The training of regional anaesthesia, however, requires the trainee anaesthetists to accustom themselves to the process predominantly in cadavers and in turn to improve their performance through repetition in real patients [7]. Although the first section of training presents the complexity of the human nerve anatomy, it does not offer any feedback - visual auditory or haptic - to the user with regard to the efficiency or effectiveness of the anaesthetic injection.

Adhering to the above observations we developed a highly detailed 3D model of human nerve-system extending from the cervical region to the upper limbs. The accurate visualization of the interscalene grove was of utmost importance as it would allow the trainee to accurately localise the landmarks for optimal catheter placement. In turn, we developed a prototype Human Computer Interface (HCI) that could accommodate transparency of different muscles and skin in order to provide the user with the optimal spatial awareness and proximity estimation of the needle to the targeted nerves. Additionally, a colour-coding has been applied to highlight the affected regions from the anaesthetic (i.e. skin and related muscles). These could be viewed in a real-time 3D environment.
A preliminary user trial and evaluation of the prototype simulation system offers great promise with the derived results indicating better anatomy understanding and spatial awareness.

The paper overall describes the development process of the simulator and the HCI and presents the results of the comparative study. In future work, we aim to enrich the realism of the regional anaesthesia training simulator with the development of a dedicated haptic feedback interface and additional functions to the existing HCI.

2. CONTEMPORARY REGIONAL ANAESTHESIA TRAINING

Brachial plexus blocks are frequently used in upper extremity surgery as well as in the management of chronic upper extremity pain syndromes. The brachial plexus is responsible for cutaneous and muscular innervation of the entire upper limb with the exception of the trapezius muscle and a small area of skin near the axilla [6,7].

Despite the block technique itself being fairly uncomplicated, the complexity of the regional anatomy presents a problem in the training of junior anaesthetists. This stems mainly from the complex anatomical drawings for the brachial plexus, commonly found in traditional anatomy training manuals, which present an overly complicated arrangement of the different nerve roots, trunks, divisions, cords and branches. In addition to that, the plexus is found in close proximity to the main vascular structures of the neck, lies superior to the lung and adjacent to the phrenic nerve and in its proximal segments it is just lateral to the cervical epidural and subarachnoid spaces as depicted in Figure 1.

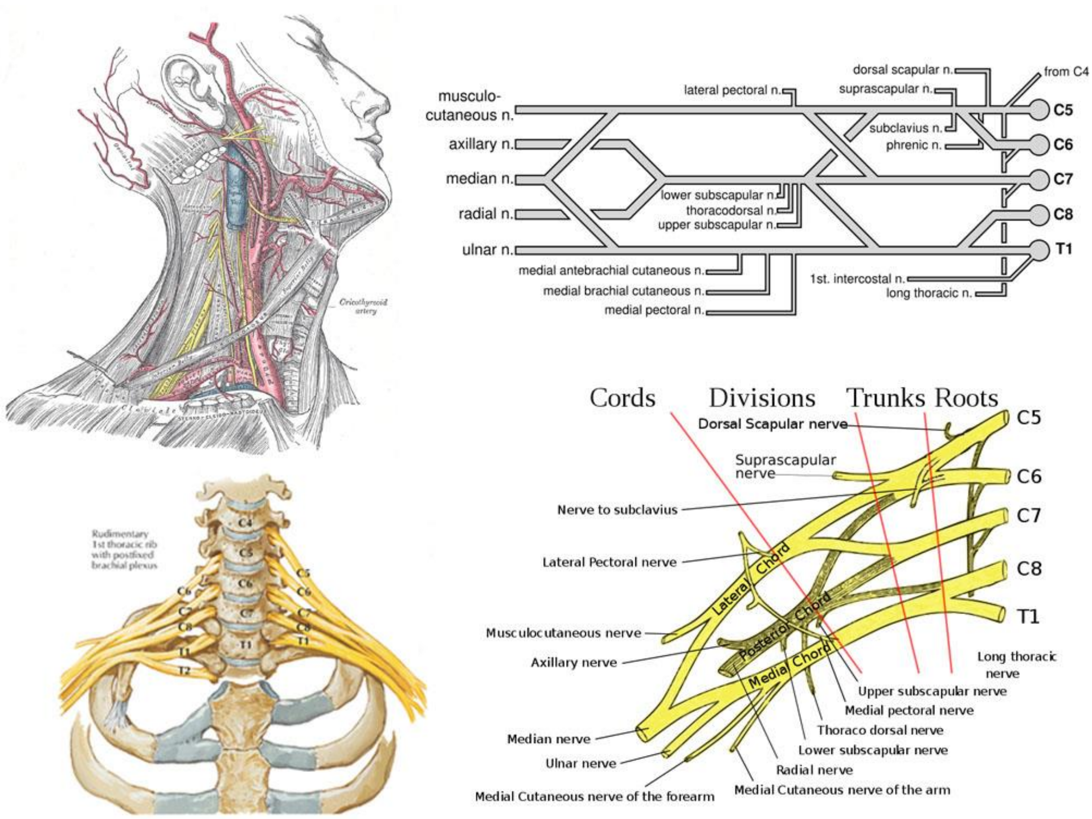

Figure 1: Contemporary illustrations and diagrammatic depictions of the brachial plexus region.

As inferred from the aforementioned, the potential pitfalls in a brachial plexus block may include vascular damage or accidental anaesthetic injection in the vertebral with subsequent seizures, pneumothoraces, paralysis of the hemidiaphragm if the phrenic nerve is inadvertently involved or even high spinal anaesthesia respectively.

The recently adopted combination of the traditional technique with ultrasound guidance allows better visualisation of the regional anatomy and provides a roadmap for avoiding such pitfalls. It does introduce, however, an extra obstacle for the trainee anaesthetist in that it creates an environment through ultrasound that is hostile to most clinicians. The anatomical depiction of relevant structures although accurate and obtained in real time lacks in image quality and requires familiarization with the equipment and with the depiction of structures in grey scale in order to be of clinical use. Correlation of the ultrasound image with a 3D image of the relevant anatomy with an accurate depiction of the positioning of the probe in respect to the relevant anatomical skin landmarks provides the trainee with an integrated system for knowledge and skill consolidation. Furthermore, it provides, through simulated scenarios, a “safe space” for trial and error.

3. SYNTHETIC VS. REAL OPERATING ENVIRONMENT

Within medicine, the difficulties of using cadavers are well recognised, however they have remained the gold standard as they allow dissection i.e.: physical interaction, and closely resemble the living human. More recently has come the opportunity to complement this method with the employment of 3D models presented in an augmented-reality operating environment. Their function would preferably be supplementary to core anatomical teaching in the first instance but nevertheless, offer an exceptionally flexible and powerful tool. In simple practical terms this newly acquired technological “instrument” would also obviate some of the difficulties that medical practitioners have in obtaining human material.

An analysis of the above observation forms an initial definition of the two approaches. As stated above the traditional cadaveric training for anatomy and surgical rehearsal offers the closest realism to a surgical operation. However, the cadavers differ from living patients as the chemical treatment necessary for preservation remove essential attributes such as different tissue textures colours and the presence of fat. Both factors can depict a misinterpreted understanding, as the dominating colour is a dark yellow, which does not resemble even remotely to the plethora of colours found in the human body during an operation. Due to the aforementioned treatments, the elasticity of tissues (i.e. skin, muscles, tendons and organs tissues) also appears to have a uniformity, which does not reflect the variety of a live body. However, the cadaver still remains a training method, which offers the ability to interact physically in real scale, which is a very important attribute for anatomists and surgeons. In addition, the cadaveric pro-sections were accompanied by anatomical texts, photographic atlas’ publication and didactic PowerPoint presentations, which could not convey effectively the three-dimensional complexity of the human forms.

Additionally, specific regions have to be viewed out of context due to their anatomical inaccessibility, fragility or the requirement of extensive skilled dissection. These areas are often only seen by trainees as two-dimensional images in textbooks and projected presentations. In contrast, the synthetic environment cannot possibly imitate the degree of physical interaction and realism provided by a cadaver. However, such an environment equipped with a flexible human-computer interface can enable the user to interact with the 3D human model in infinite ways. In particular, complicated anatomical issues can be visualised intuitively by a VR interface, which does not have any physical constraints [5]. Hence it is possible for the user to interact freely with a volumetric 3D model, selecting their own number of infinite viewpoints, a factor suggested being central in spatial anatomical understanding [3,4]. Note that synthetic, virtual and augmented reality definitions would be used indistinctively throughout the manuscript and referring to the same type of artificially generated environment.

Initial trials with respect to interface designs for VR systems have indicated that such interfaces may enhance significantly user’s spatial awareness resulting in faster knowledge accumulation of anatomical structures [1,2,3,4]. Building upon this encouraging past experience, in this work we entertain the possibility of expanding the HCI attributes to provide the trainee doctor with customisable information regarding the section of interest. However, another potential issue in such interfaces is the realistic replication of physical tactile feedback. This could be considered challenging due to the complexity of the algorithms required for different operation modules and different elasticity of the tissues, (i.e. skin, muscles etc.).

For the development of the proposed system, we adhered closely the information provided by the consultant Anaesthetists and observed the contemporary training methods in this much specialised yet immensely upcoming field. Through this meticulous examination, it became obvious that the major issue was the correlation of the Ultrasound imaging onto the human body. To this end, the anaesthetist has to interpret the 2D monochrome image presented by the Ultrasound device and guide in his/her needle through the three-dimensional human body.

4. CONTEXT DEVELOPMENT & HUMAN DIVERSITY

Mindful of the aforementioned suggestions from the anaesthetists and radiologist involved, we opted initially for a realistic, yet stylised 3D representation of the human body, which would offer an uncluttered view (i.e. simplification of vein artery and nerves' routes) of the organs under investigation. The primary target of the evaluation was to highlight the spatial relationship between different layers, organs and structures of the body. The derived high-fidelity 3D representation of the head and neck area was focused to complement an existing activity-based curriculum. Notably, contemporary studies utilised a volumetric translation of MRI scans in order to produce the 3D human model [8]. Our approach employed all possible information resources available including MRI, CT, Ultrasound still images and videos, and specialised bibliography so as to model the specific section as faithfully as possible [7].

During the implementation of such complex structures, we stumbled upon a general issue that hinders all the 3D anatomical models and simulations which lay upon the diversity of the human race. Evidently, the literature presents a plethora of variation in the positioning, sizing and spreading of all the different supply systems of the human body [9]. As the nervous system is no exception to this plurality, we selected to depict the most common structure of brachial plexus although this would represent only a 50% approximately of the human diversity. Notably, the development of a "definitive" 3D human model for simulation purposes would be by definition lame, as it is impossible to delineate which might be the "accurate" or the "definitive" combination. Being aware of the aforementioned observation we developed the "most common" positioning of the brachial plexus nerves for this pilot study. For a complete simulation system, we would opt for the development of the entire spectrum of the major nerves' positioning, as supplementary simulation scenarios might deem necessary.

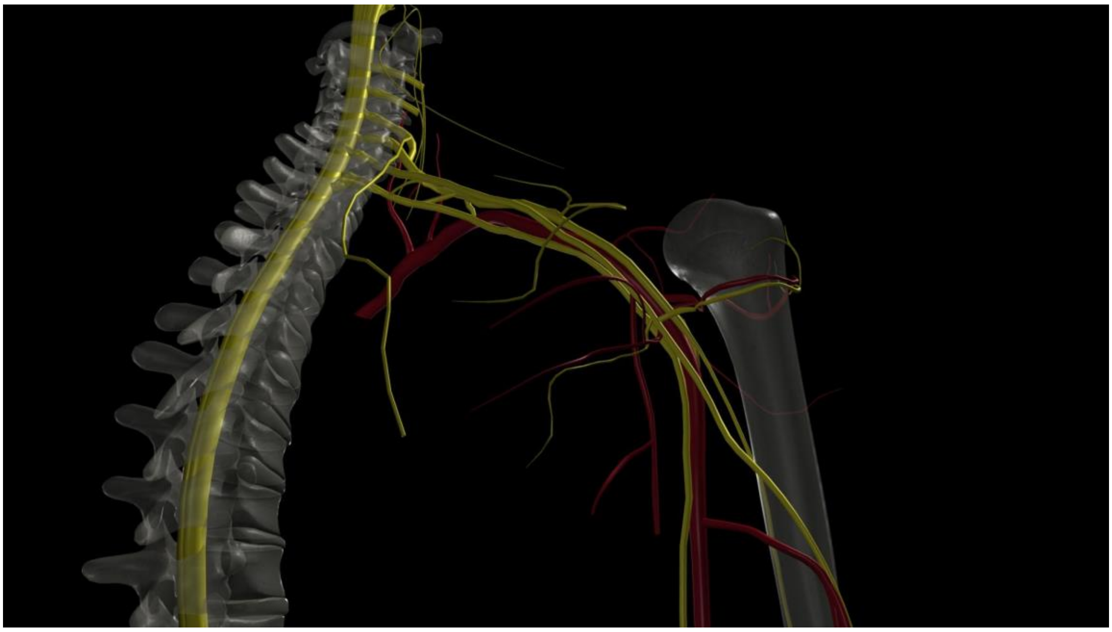

Figure 2: Screenshot of data manipulation; Examination of high-fidelity visual representation of the medial, ulnar and radial nerves as well as the neighbouring structures.

While the complexity of the human data was simplified, we gave particular emphasis to details that were absolutely relevant to the nerve blocking process. To this end, specific areas of the anatomy under investigation were elaborately developed with the constant input of information provided by all the participating medical doctors. This exemplifies the importance of this collaborative methodology, and indeed the difference between taught and surgical operative anatomy. From a technical point of view, the final 3D model had to be extensively investigated and remodelled in order to provide an acceptable refresh rate in the projection. Hence the polygon numbers kept to the minimum possible level that could satisfy the quality of the projection as well as the smooth structural coherence of the different structures, as Figure 2 illustrates above.

5. HCI REQUIREMENTS

In order to enable the medical practitioners to use effectively the provided model, we opted for an application which could switch seemingly between layers and provide transparency to the required sections as depicted in Figure 3. These functionalities although common in the majority of the standard 3D packages are not as commonly used in real-time VR applications. During the 3D modelling of the selected region, the medical practitioners highlighted the important functionality of layers and the selective transparency. As such the trainees can see through the different layers of skin and muscles and create a three-dimensional mental map of the region that they wish to anaesthetise.

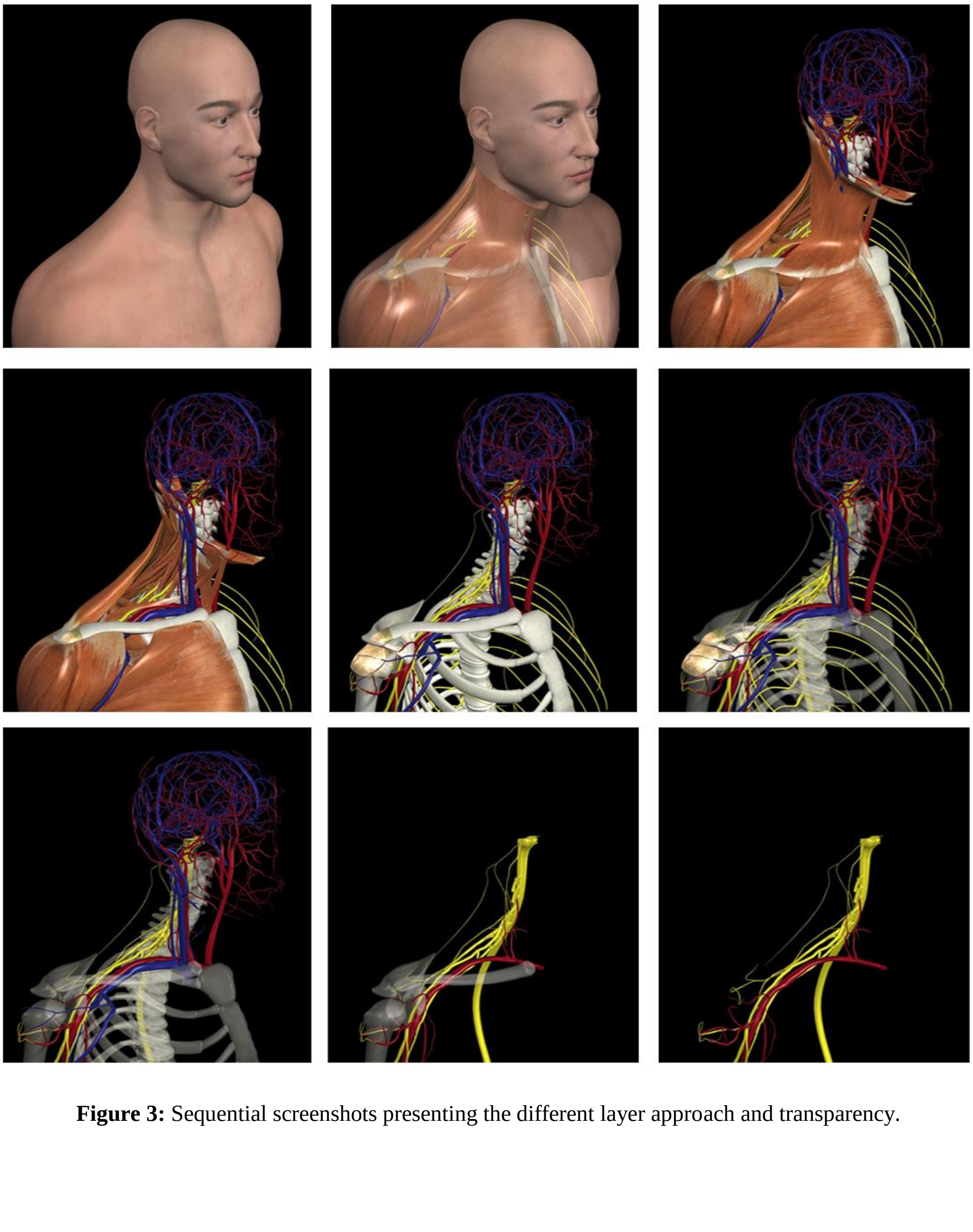

Figure 3: Sequential screenshots presenting the different layer approach and transparency.

Although the 3D depiction is very informative with regard to the anatomical form of the section it is unclear to the users to which extent they position their needle and if they correlate properly the Ultrasound image to the actual needle penetration. To this end, it was deemed essential to incorporate a simultaneous presentation of the Ultrasound image to the 3D model. This combination offered a clear understanding of what actual parts of the human body are depicted to the Ultrasound black and white imaging display. Furthermore, the 3D visualisation of the penetration demystified the regional anaesthesia process of the brachial plexus section. This combinatory approach is presented clearly in Figure 4.

Figure 4: Combination of 3D model and Ultrasound imaging.

6. DISCUSSION

Although the visual correlation has been developed successfully, we deemed essential to producing simulated haptic feedback during the regional anaesthesia injections.
n was closely informed by the constant feedback of consultant anaesthetists and interventional radiologists. The hardware comprised a six-degree of freedom PHANTOM arm. The system was run by a high-end PC which was presenting the simulated environment in a 23-inch monitor and in a large projection screen as depicted in Figure 2. This was deemed ideal for accommodating larger groups of trainees which could watch closely the demonstration by the consultant doctor before their individual attempts. From a training point of view, this group exposure to the simulation scenarios offered a smooth induction to the process and increased substantially the familiarisation process.

The 3D model of the body was developed with the use of Maya and followed data of CT, MRI scans and existing 2D teaching material provided by the medical doctors. The model was in purposed divided into layers so as to enable the infusion of interactivity and functionalities on each individual layer or in groups as described explicitly above. In turn, the complete 3D model had to be optimised for use in real-time simulation and in Virtual Reality environments. The environment development and the aforementioned simulation attributes were in turn programmed with the use of VEGA software suite.

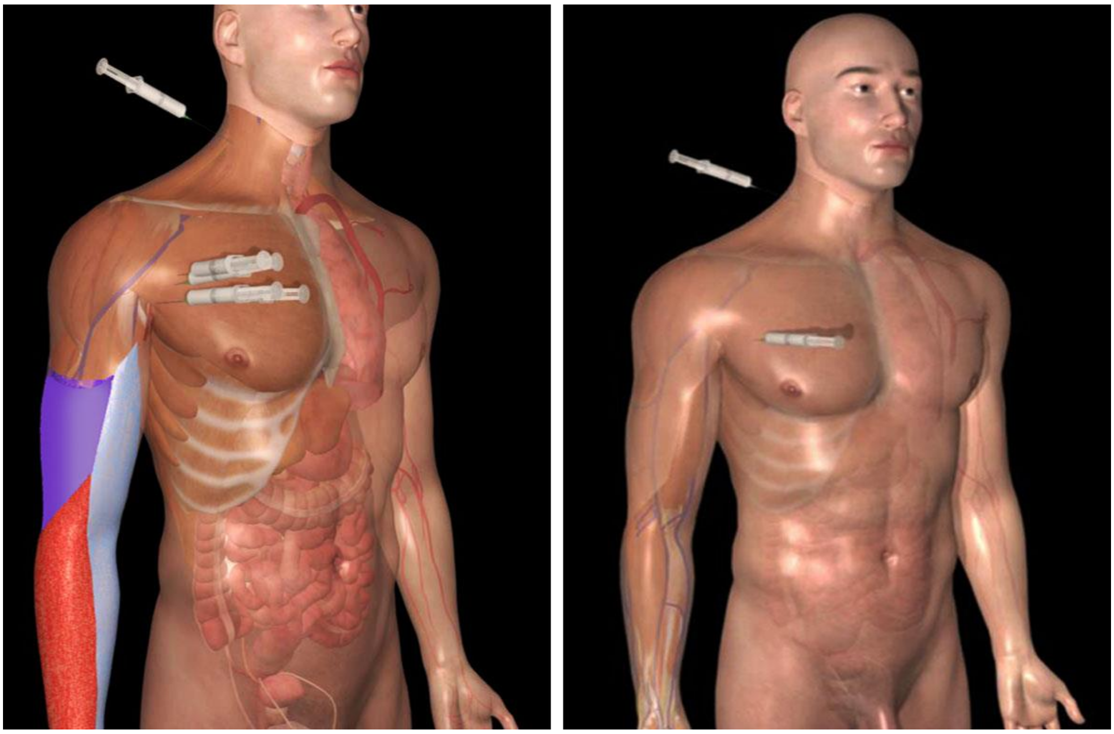

Figure 5: Indicative positioning of needles for different nerve blocks in a VR environment.

8. CONCLUSIONS

This paper describes an important role for Virtual Anatomy in operative surgical training. In addition, through the development of appropriate, focused anatomical models we have explored important issues pertaining to the design of practical applications to augment surgical training. Previous work in this area has highlighted the importance of the human-computer interface as a barrier to successful uptake of this technology into mainstream training. The modern trainee at this time remains reliant on inadequate cadaveric exposure, limiting two-dimensional resources and inappropriate opportunistic learning through incisional 'windows' in the living patient. In this study, we illuminated useful approaches to intuitive design aiming to allow trainees and trainers to maximise learning outcomes. The suggested interface utilises simplicity to convey as seamlessly as possible the spatial information, facilitates interaction and limits extraneous and unnecessary data while achieving the required fidelity. The validation clearly identifies weaknesses in the choice of haptic devices but identifies strongly a place for further research into intuitive interfaces that may facilitate the implementation of practical, focused surgical training applications.

References:

1. Charissis V., Ward B.M., M. Naef, Rowley D., Brady L. and Anderson P., An Enquiry into VR Interface Design for Medical Training: VR Augmented Anatomy Tutorials for Breast Cancer, in Proceedings of the International Annual Symposium of SPIE, 27-31 January, San Jose, California, USA, (2008).

2. Sakellariou S., Ward B. M., Charissis V., Chanock D., and Anderson P., Design and Implementation of Augmented Reality Environment for Complex Anatomy Training: Inguinal Canal Case Study, in Proceedings of the Human-Computer Interaction International 2009, San Diego, California, USA, (2009).

3. Sakellariou S., Ward B.M., Charissis V., Chanock D., and Anderson P.: Design and Implementation of Augmented Reality Environment for Complex Anatomy Training: Inguinal Canal Case Study, Book title: Human-Computer Interaction. Interaction Platforms and Techniques, Lecture Notes in Computer Science, Volume 5620/2009, pp 550-559, Springer Berlin/ Heidelberg, ISBN 978-3-642-02808-3, (2009).

4. Ward, B.M., Charissis, V., Rowley, D., Anderson, P., & Brady, L.; An Evaluation of Prototype VR Medical Training Environment: Applied Surgical Anatomy Training for Malignant Breast Disease, in Studies in Health Technology and Informatics, Volume 132, pp 550 – 555, Ios Press, (2008).

5. Naef, M., & Payne, J.: AutoEval mkII - Interaction Design for a VR Design Review System. Proceedings of IEEE 3DUI Charlotte, North Carolina USA, (2007).

6. Marhofer P., Greher M. and Kapral S., Ultrasound guidance in Regional Anaesthesia, in British Journal of Anaesthesia 2005 94(1):7-17, (2005).

7. Meier G., Buettner J., Peripheral Regional Anesthesia, An Atlas of Anatomy and Techniques, Georg Thieme Verlag, (2006).

8. Gorttke et al., Virtual-reality based simulator for training in regional anaesthesia, British Journal of Anaesthesia, International Journal of Anaesthesia, C.S Reily (Ed), Vol 103, No 4, Oct 2009, ISSN 0007-0912, (2009).

9. Christophe J. L., et al., Assessment of topographic brachial plexus nerves variations the axilla using ultrasonography, British Journal of Anaesthesia, International Journal of Anaesthesia, C.S Reily (Ed), Vol 103, No 4, Oct 2009, ISSN 0007-0912, (2009).

10. Hara, M., Asada, C., Higuchi, T. & Yabuta, T.: Perceptual Illusion in Virtual Reality using Haptic Interface. In: IEEE Proceedings of IEEE VRSJ International Conference on Intelligent Robots and Systems, Sendai, Japan. (2004).

11. Sang-Hack, J., & Bajcsy, R.: Learning Physical Activities in Immersive Virtual Environments. In: IEEE Proceedings of the International Conference on Computer Vision Systems, ICVS '06, St. Johns University, Manhattan, New York City, USA, (2006).

12. Crossan, A., Brewster, S., Reid, S. & Mellor, D.: Multi-Session VR Medical Training – The HOPS Simulator, in the Proc. of British HCI Conference, London, UK, pp 213-225, Springer, (2002).