Using virtual reality for medical diagnosis, training and education

A H Al-khalifah[1], R J McCrindle[1], P M Sharkey[1] and V N Alexandrov[2]

[1]School of Systems Engineering, the University of Reading,
Whiteknights, Reading, RG6 6AY, United Kingdom

[2]Advanced Computing and Emerging Technologies Centre, the University of Reading,
Philip Lyle Building, Whiteknights, Reading, RG6 6BX, United Kingdom

a.h.al-khalifah@reading.ac.uk, r.j.mccrindle@ reading.ac.uk,
p.m.sharkey@ reading.ac.uk, v.n.alexandrov@ rdg.ac.uk

[1]*www.sse.reading.ac.uk,* [2]*acet.rdg.ac.uk*

ABSTRACT

In this paper we present a number of the immersive VR applications that we have developed during the past 18 months as a means of practically demonstrating the modelling approaches previously reported. The paper discusses the usefulness of the different approaches in assisting medical practitioners to diagnose and track conditions which might lead to impairment or disability, and how they can be used to train medical students to recognise such conditions or to undertake associated medical procedures. Initial findings of a survey of undertaken with medical practitioners as to the effectiveness of VR and in particular immersive models as diagnostic and training aids are also presented.

1. INTRODUCTION

To assist medical students in their understanding of anatomical structures or medical procedures, three-dimensional (3-D) virtual models can be used which offer a number of advantages over traditional 2-D images, plastic models and cadavers. For example, 2-D images have the inherent problems of limiting the view to one angle and obscuring important details; plastic models have the limitation of not presenting the fine detail; and cadavers are expensive to obtain and maintain, while their use may raise ethical and moral questions for some people. Digital 3-D models however can be accessed electronically and interacted with in order to enhance understanding. Immersive virtual reality devices such as CAVE-like environments (Cruz-Neira et al 1993) can further enhance this interaction and understanding as well as allowing collaboration to occur both locally and at a distance. General models for display within immersive environments can be generated using library data such that available from The National Library of Medicine's Visible Human Project (NLM 2006). Alternatively, data for individual patients can be displayed, obtained for example, from imaging scans.

At ICDVRAT 2004 (Al-khalifah and Roberts 2004) a number of modelling approaches for medical simulation were presented. In this paper we present a number of the immersive-based VR applications that we developed during the past 18 months in order to practically demonstrate such approaches. We consider the usefulness of these models to be in areas such as assisting medical personnel to diagnose debilitating conditions which might lead to impairment or disability, for monitoring improvement of a patient after therapy; and in training medical students to recognise particular conditions and other medical structures. With regard to this, initial findings of a survey of medical practitioners as to the effectiveness of VR and CAVE-like environments as medical training and diagnostic aids are presented.

2. VR MODELLING APPROACHES

A number of benefits can be gained through using models within immersive CAVE-like environments. For example, trainees, educators and/or practitioners do not need to be in the same physical environment to view and interact with the model. A demonstrator for example, can be in a remote location working via a virtual interface whilst sharing their model(s) with students or other practitioners who are located elsewhere in a CAVE-like display. Interaction with models in the immersive environment may also be more intuitive than

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that with traditional 2-D models and they may also allow the user greater freedom of movement and ability to explore structures from multiple viewpoints. Practitioners can for example interact with the model(s) to explain anatomical structures or the symptoms of progressive illnesses such as glaucoma to the students. Time progressive models of an individual patient's brain scans could also be displayed to help practitioners monitor the effects of treatment and recovery of that patient over time, for example after suffering brain trauma from an accident.

Approaches such as polygonal, iso-surface and volumetric modelling techniques can be used to represent different types of medical conditions, procedures or structures. Decisions as to which approach is the most appropriate for a particular medical situation can be made by considering the properties of the different models.

Polygonal (surface) modelling focuses on creating abstract representations of structures and as such requires far less computational resources than other forms of rendering. Polygonal representations are artistic impressions of models created by the developer, composed of a set of polygons, and with accuracy and smoothness of the models governed by the number of polygons. This type of modelling allows developers to create structures according to their requirements in terms of shape and accuracy making them suitable for modelling human body structures and anatomical representations. Polygonal representations are fast to render, but this gain in speed comes at the cost of a loss in accuracy.

Iso-surface modelling (indirect volume rendering) is another common modeling approach in medical visualization and simulation implementations (Lorensen et al 1996; Gingins et al 1996; Kalra 1995). This procedure involves the generation of surfaces from volumetric data. The process follows a segmentation stage, which extracts the desired material surface from original volumetric data. Rendering speeds of such implementations are normally increased due to the dramatic reduction in data size. Surface texture mapping is another advantage that allows the addition of realistic images obtained from real organs to the surface of the model to enhance appearance. However, such high rendering speeds and aesthetic appearance of the models come at the price of a loss of internal data representations.

Volumetric modelling (volume rendering) is a visualisation technique (Kaufman et al 2000, 1993a, b; Gibson 1998), where 3-D models of human organs are generated from scanned images, such as Magnetic Resonance Imaging (MRI), Computer Tomography (CT), or Positron Emission Tomography (PET) scans. These images are then displayed as high quality voxel-based 3-D volumetric models. The main advantage of such a procedure is the ability to preserve original anatomical structures and details from original data. Its main drawback however is the need for powerful computational systems to handle the large quantities of data involved. Such conditions have serious implications on rendering speeds of the models and the required massive storage capacities to hold such data.

A number of medical applications have been developed to explore the issues associated with each modelling approach.

3. THE APPLICATIONS

Medical diagnosis, training and education activities can involve all of the above mentioned techniques, but they vary in the degree to which they can be effectively used and how they can be applied. Simulation, modelling and visualization are the main techniques that can be employed and a number of immersive virtual training applications have been developed, each one offering unique characteristics. In particular the 3-D models developed allow local and remote users to interact in real time with the models and for discussions to be shared amongst users. For demonstrative and educational purposes both polygonal and iso-surface modelling approaches were also adopted in this work. A number of the applications developed are briefly described below.

Polygonal modelling was used to develop the virtual eye shown in Figures 1 & 2. (Webb et al 2003). This application enables practitioners and educators to study the anatomy of the eye for educational purposes and also to observe how progressive illnesses such as glaucoma may develop over a period of time.

Polygonal modelling was also used to develop the hip replacement application (Figure 3) which can be used to demonstrate the anatomical structure of the hip and to allow students to practice the procedures that would be involved in carrying out such an operation.

Iso-surface modelling was used to create knee and brain applications for both anatomical demonstration purposes and diagnostic tools (see Figures 4 & 5). The particular advantage of both of these applications is

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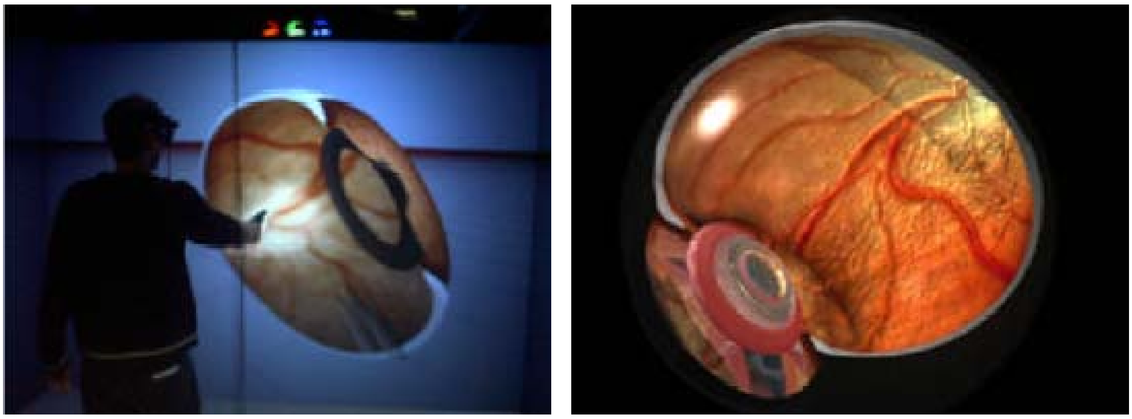
that they represent accurate and realistic structures generated from real human body data scans. This allows practitioners to examine real organs of the human body and inspect possible traumas or deformities.



Figures 1 & 2. *The model of the eye. User interacting with the model (left). The model is clipped for better inspection (right). These images appear courtesy of [Webb, 2003].*

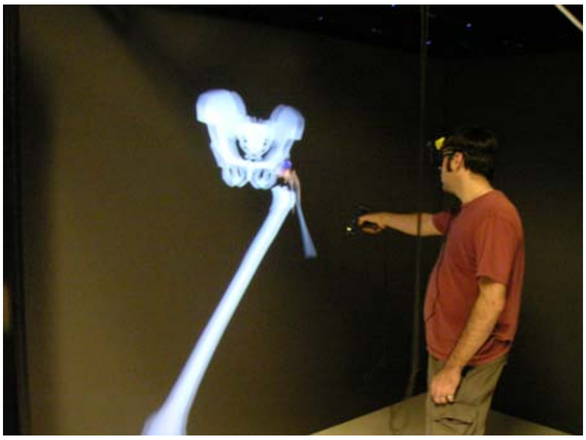
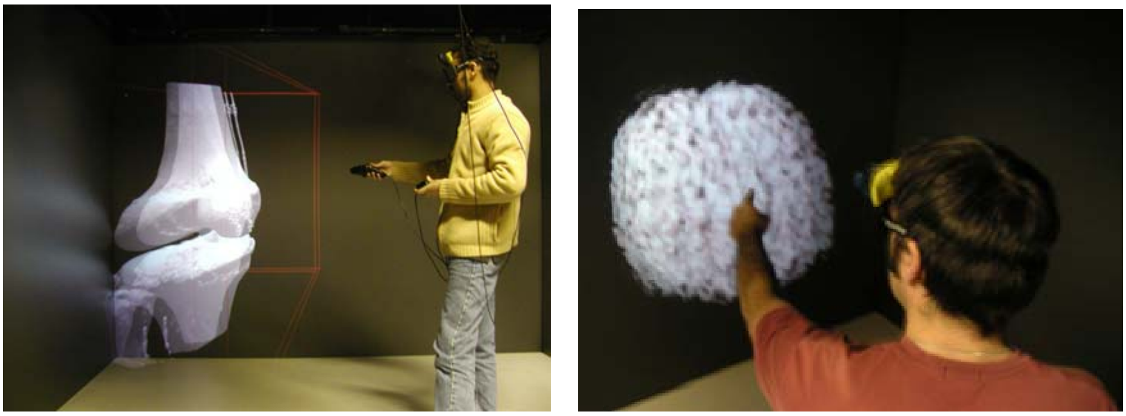
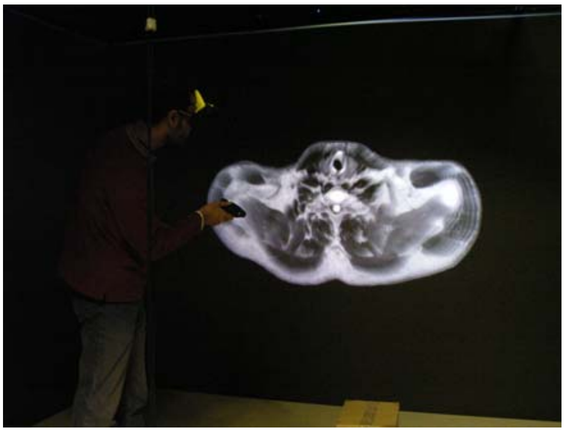


Figure 3. *User demonstrating a hip replacement procedure.*



Figures 4 & 5. *An isosurface model of the knee (left) and isosurface model of the brain. Users inspecting and interacting with models.*

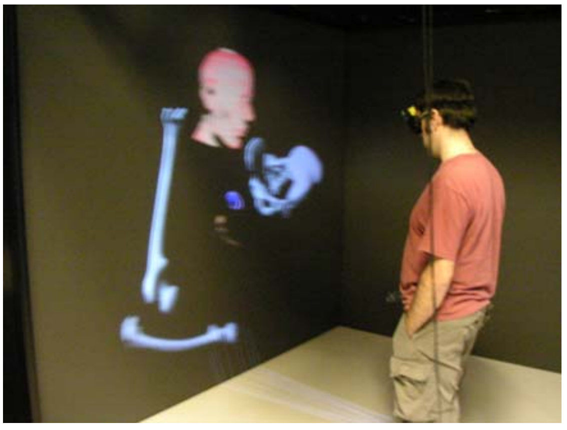
Human head and brain applications were also developed using volumetric modelling as diagnostic tools (see Figure 6). The National Library of Medicine's Visible Human Project (VHP) datasets were also displayed in some of our immersive applications including those of the male thorax as shown in Figure 7. It was felt important to ensure that this dataset could be modelled within the immersive environment as it forms a scientific archive of medical datasets for educators and professionals working in the field of medical visualization.



Figures 6 & 7. *User examining a volumetric model of the human head (left).User interacting with the thorax volumetric dataset from the Visible Human Project (right).*

For simulation purposes, open surgery applications was also considered in the development phase of this work. Demonstrations of basic deformation and open surgery procedures were implemented as shown in Figure 8. This includes the opening of the abdominal area and the inspection and interaction with organs such as the stomach and kidneys.

In order to compare different anatomical structures and study the human anatomy from different perspectives and levels of detail, a combined modelling approach was also adopted in order to create an educational application that demonstrates an anatomical structure of the human body using the three different modelling approaches (polygonal, iso-surface and volumetric) as shown in Figure 9.



Figures 8 & 9. *Internal parts of the human body exposed following the deformation of the abdominal cavity (left). User interacting with different human body parts modeled using different modelling techniques (right).*

Because collaborative education is a critical tool in distance and local learning, networked applications were also developed to allow collaborative tasks to occur such as the sharing of models and datasets. In this instance of an educator being in a remote location, working on a virtual interface whilst sharing this model and its constituent parts with students, the educator performing the actions on the model/models can be seen by the students as an avatar representation.

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4. THE STUDY

In order to gain feedback on our applications and to ascertain the views of practitioners on the applicability of virtual reality for medical training, diagnosis, and surgery planning, two studies were conducted based on questionnaires and CAVE-based demonstrations.

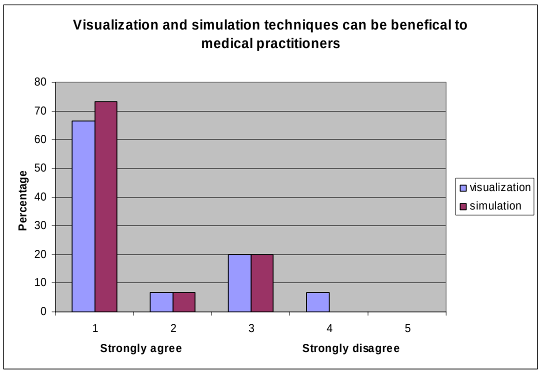
In the first study views from 16 medical professionals (Group A) including surgeons, general practitioners, medical consultants, clinical engineers, clinical skill directors and medical educators were obtained. The participants in this group were familiar with VR technology and were also given a 20 minute demonstration session inside the immersive display where they had the opportunity to interact with a number of our medical applications ranging from diagnostic (volumetric) to educational (polygonal and isosurface) models. Following this display they were given a questionnaire to complete.

In the second study feedback was sought from 12 medical practitioners (Group B) including medical consultants, general practitioners, researchers, surgeons, and medical educators who differed from Group A in that they had no prior knowledge or experience of virtual reality. Nor did this group receive an immersive demonstration of the applications although the questionnaire did have a number of related images attached.

The questionnaires covered issues relating to the applicability of VR technology in general, and the immersive display in particular, to medical education, visualization and simulation. Questions relating to the effectiveness of the immersive technology within the simulation and education processes compared to desktop devices were also considered but are not reported here.

5. RESULTS AND DISCUSSION

The partial outcome of these studies, comparing the perceptions of the two groups on the usefulness of VR to medical practitioners is outlined below:



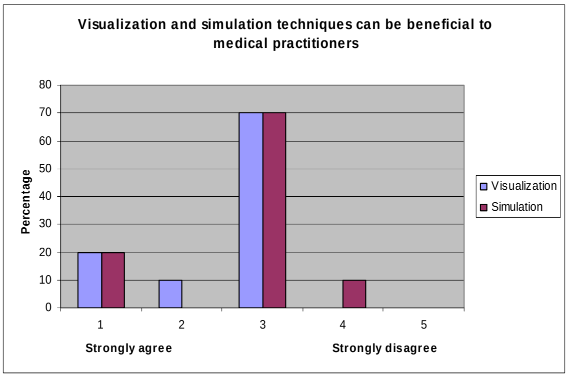


Figure 10 (Group A) & Figure 11 (Group B) – *are visualization and simulation techniques beneficial to medicine?*

Figures 10 and 11 give the overall responses from participants being asked if they considered whether visualization and simulation techniques could be of benefit to the medical profession. Here we note that Group A, who had experienced first hand the immersive VR application demonstrations responded much more favourably than those in Group B who had not seen the demonstrations.

Figures 12 and 13 show the breakdown of the usefulness of the different modelling techniques -volume, iso-surface and polygonal (surface) - for medical applications as perceived by the two groups. Once again participants in Group A tended to perceive the benefits of the different modelling approaches more strongly than those in Group B but even here very few respondents thought that they would be of no use at all. Both groups tended towards volumetric modelling as being the approach that offered the greatest potential for use in medical applications possibly due to the amount of data that can be displayed using this technique.

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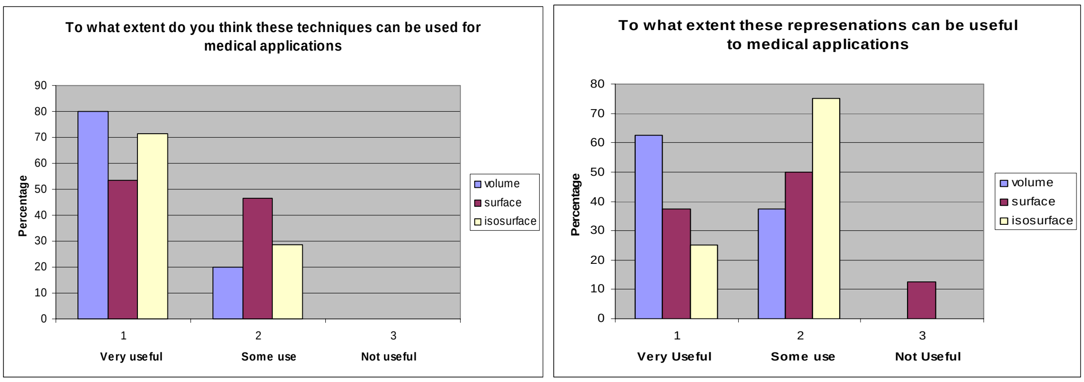


Figure 12 (Group A) & Figure 13 (Group B) – *extent to which different modelling techniques can be used for medical applications*

Figures 14 and 15 explore in more detail the perceptions of the two groups into the effectiveness of the immersive display rather than VR in general. Once again Group A who had the opportunity first hand to experience the immersive nature of the applications respond more favourable to the question, whilst those in Group B were more unsure as to the benefits. It should be noted however that none of the Group B respondents responded negatively to the question.

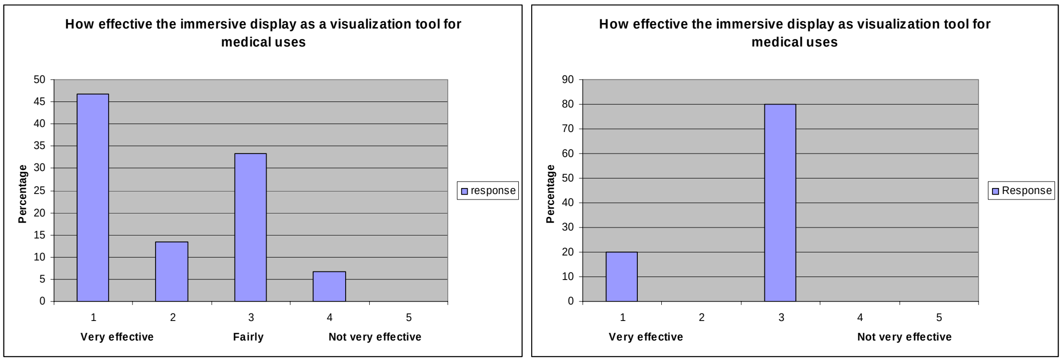
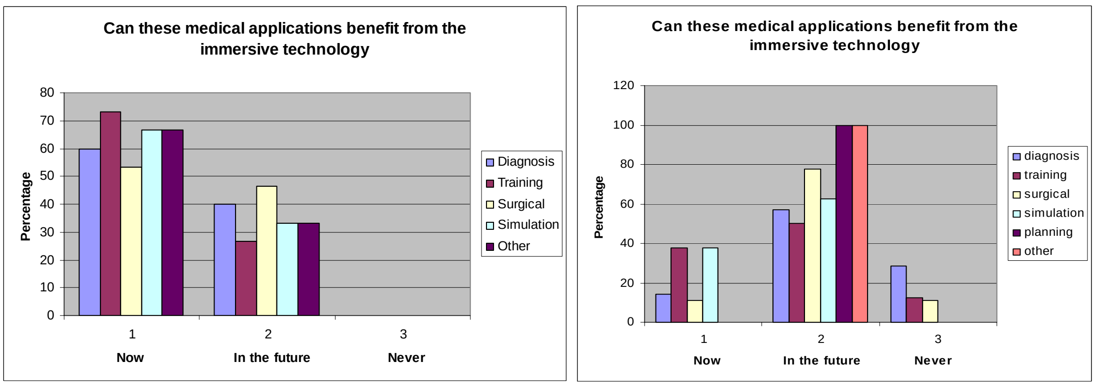


Figure 14 (Group A) & 15 (Group B) – *the effectiveness of immersive display technologies as visualisation tools.*

Figures 16 and 17 look in more detail at the type of applications (diagnosis, training, surgical procedures, simulation etc.) the participants believed could most benefit from immersive technology.



Figures 16 (Group A) & Figure 17 (Group B) – *what applications can benefit from immersive technology?*

Group A participants on the whole see the application of the technology to medicine as being much more in the present than those in Group B who see it as a technology for the future. Only a small number of Group B participants and none of Group A participants believe that there will never be any benefit from using immersive technology for medical applications. There seems to be some scope for immersive VR to be used

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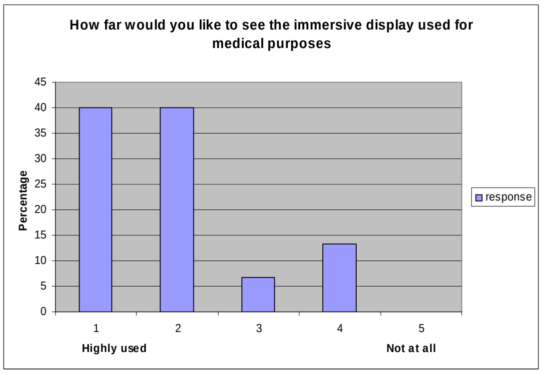
for the range of medical applications – diagnosis, training, surgical procedures, simulation, planning and other non-specified applications.

Group A were also asked about the degree to which they would like to see immersive displays used for medical purposes; how effective they saw immersive displays as visualisation tools and for medical simulations; and whether volumetric representations could help in examining medical structures and identifying disease. Results from these questions were generally favourable and are shown in Figures 18 – 21.



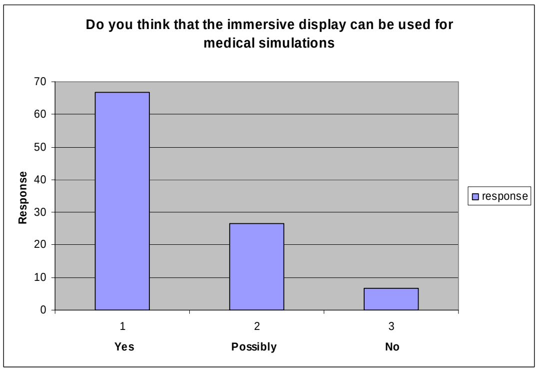
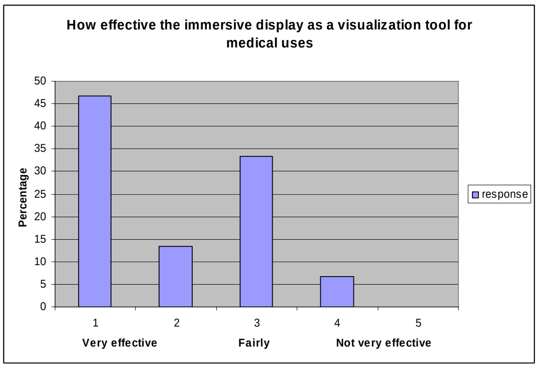
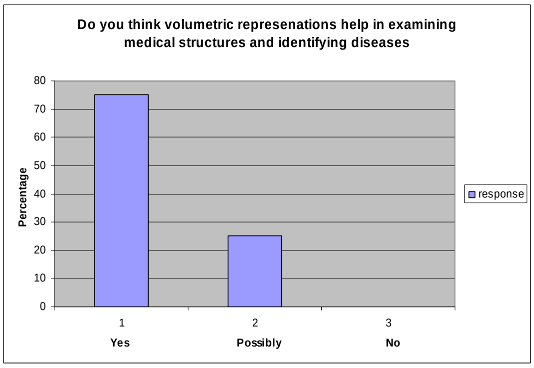


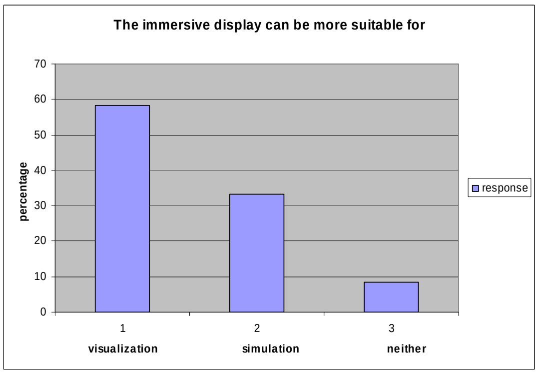
Figure 18 & Figure 19. *The desire to use immersive displays for medical purposes; the use of the immersive display device as a simulation tool (right)*

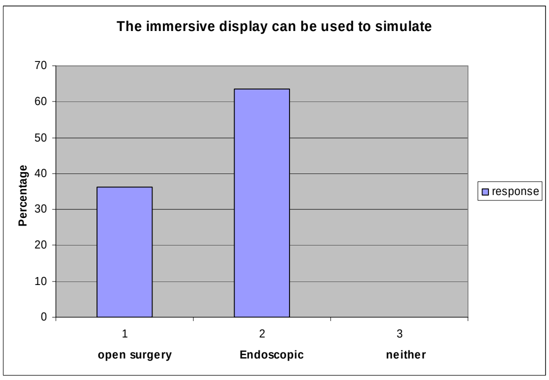




Figures 20 & 21. *The immersive display as a visualisation tool for medical uses; use of the volumetric modelling in examining structures and identifying disease.*

In Group B respondents saw the immersive display as being more useful for visualisation than simulation purposes and of these a greater proportion favoured use for simulating endoscopic procedures than for open surgery simulations as shown in Figures 22 and 23.





Figures 20 & 21. *The immersive display as a visualization tool in medicine; the immersive display device as a simulating tool for surgery (left).*

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6. CONCLUSIONS AND FURTHER WORK

In this paper a number of the immersive VR applications that we have developed during the past 18 months using polygonal, iso-surface and volumetric modelling approaches have been described. These models have been demonstrated to medical practitioners who have had the opportunity to interact with them in an immersive environment and assess their usefulness to the medical profession for diagnostic, training and educational purposes. A questionnaire was also sent to other medical practitioners who did not have the opportunity for experiencing first-hand interaction with the models. Initial findings of the survey are encouraging. However, it is interesting to note that those practitioners who received demonstrations of the applications see VR as a current technology whilst those who have not directly experienced its use see it as having potential but as a future rather than current technology. The diversity of expertise in these groups has provided us with rich and valuable feedback on the application of VR in general and immersive technology in particular for various medical applications including modelling for education, visualization for diagnosis and simulation for training. Further work is currently underway with regard to ascertaining students perceptions of VR as a teaching medium.

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