Medical Visualisation Feasibility Study

FINAL REPORT

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Promoting further and higher education

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Ian Parkin

‘A thorough understanding of anatomy is one of the crucial elements in ensuring safe, efficient medical and surgical practice. The Medical Visualisation Network is committed to producing digital models that will be viable, economical and highly efficient additions to teaching resources forboth undergraduate and postgraduate training’

Bertie Wood

‘In the short time since the MVN came into existence, it has proved that a technological approach to anatomy teaching, which enables more rapid learning and superior comprehension. The introduction of movement to what traditionally has been a still subject allows huge educational advantage, as does the ability to build up body areas and layers. There are certain implications for medical undergraduate and postgraduate training, but also, and perhaps still greater, implications for the training and professional development of students and staff across a far wider spectrum including Nursing, Physiotherapy, Radiography, and the Paramedical Groupings. At present there is need for further financial underwritingn of a technology which may be sufficiently promising to add to Scotland’s internationala standing’

David Rowley

‘We have only touched the surface of the potential of this project and a continuation of the network will have genuine benefits in terms of patient safety; the way we teach and learn; and quite literally how we perceive the complexity of the human body and interact with it’

Bill McKerrow

‘In my view the work ongoing in the DDS has demonstrated the huge potential of this technology in the range of areas outlined above and is an opportunity for a Scottish initiative to impact substantially on medical education and training on a worldwide basis’

Vivienne Blackhall

‘The work of the medical visualisation network has the potential to revolutionize the way in which medical students learn anatomy. It brings anatomy to life and provides a straightforward approach to complex anatomical concepts. I wish it had been available to me during the undergraduate course!’

1. Introduction

This Feasibility Study was conducted for one year between January 2007 and January 2008. This report recounts the activities of the twelve months, describes the scope of the study through persons and organisations contacted, presents the case studies undertaken, on-going development work and concludes with a strategic overview of the area coupled to recommendations for the future.

The four sentences below set out the original context and high level aspirations for this study as presented to the Scottish Funding Council in May 2006. As such, they represent the aspirations against which the success of this Study should be measured.

> Traditionally, the only means medical practitioners have had to view real three-dimensional structures of the human body have been in the form of patients and cadavers. Now, however, advances in 3D visualisation technologies are making it possible to view and interact with such structures without the need or reliance on the use of real people or body parts.
>
> The ability to take vast quantities of existing two-dimensional sectional data, and render it into realistic interactive three-dimensional images has the potential to affect profound changes in medicine in terms of teaching, learning and cognition.
>
> The Digital Design Studio, together with the Royal College of Surgeons of Edinburgh, envisage the need for a sustainable, long-term network that will identify the key areas in future practice-based research in which 3D visualisation and interaction can support medical learning and teaching, surgical planning and rehearsal.
>
> Such a network of clinical practitioners, academics and visualisation experts with an interest in interactive real-time imaging, simulation and reusable learning objects, together with a natural constituency of medical schools and royal colleges, would provide Scotland with a profile in medical visualisation consistent with its existing international standing in medicine.

(Digital Design Studio, submission for funding, May 2006)

2. Executive Summary

The discussions that took place between the Digital Design Studio and the Royal College of Surgeons prior to submitting the application to the SFC for funding in May 2006, gave grounds for optimism that the time was right for an exploration into the benefits that 3D visualisation might confer to the teaching of anatomy, surgical rehearsal and training.

It is no exaggeration to say that the response to this Feasibility Study from the medical profession in general and to the formation of a dedicated Network has been overwhelming. There was an unreserved willingness and a spirit of cooperation on the part of all medical practitioners contacted to support the aims of the Study. The Study has resulted in the following achievements:

The formation of a truly inclusive network, The Scottish Medical Visualisation Network, numbering over 160 members, with representation from all of Scotland, 44 different organisations and 22 medical disciplines. This Network includes the five Medical Teaching Hospitals in Scotland, the NHS and the active participation of HMI of Anatomy for Scotland, Bertie Wood, the Royal College of Surgeons, Edinburgh and the Royal College of Physicians and Surgeons, Glasgow.

The formation of a Board of Management including leading academics, practitioners, surgeons and diagnostic experts, to agree policy and set strategy for the Network. This Board has now been renamed the Medical Visualisation Advisory Committee, and continues to guide the Network in enhancing its future research strategy and development.

The completion of five case studies in notoriously difficult fields each of which successfully demonstrated the rich potential of 3D visualisation to educate and inform where proper multi-disciplinary collaboration was developed between medical and visualisation experts. One of these, lung collapse, brought a new realisation that upturned conventional medical understanding and current teaching practice. The success of the case studies was instrumental in attracting additional funding from the Royal College of Surgeons, NHS Education Scotland, Ayr Hospital and Raigmore Hospital, Inverness.

Two, one-day Workshops the first of which introduced technology and techniques applicable to medical use and identified appropriate challenging case studies to be undertaken. The second workshop, much larger in scale, allowed the presentation of the outcomes of the five case studies. These presentations broke new ground in medical visualisation.

The publication of eight papers on the case studies given at international conferences.

Creation of a dedicated website as a vehicle for dissemination through public and members areas. The Scottish Medical Visualisation Network website has also been a means to further expand the Network and raise awareness internationally.

Recognition of significance by TV, radio and Press across the UK and internationally through articles and TV news presentations and WWW.

The Scottish medical student community, culturally versed in digital media, have approached the Medical Visualisation Advisory Committee to be part of the Network and gain further insight into their fields of study. A student member now sits on the Committee.

As important as the tangible achievements listed above, is the high level of expectation and aspiration created by the Network. This has fused as a single voice in support of results that clearly demonstrate a step change in the way that surgical procedures can be conducted and taught. The momentum thus generated demands continued support to realise the potential 3D visualisation offers in medical contexts and enhance Scotland's reputation internationally as a centre of excellence in medical teaching.

Since the end of the Feasibilty Study, funding has been secured from the Royal College of Surgeons, NES, Raigmore Hospital (Inverness), Ayr Hospital to conduct new case studies.

The work and vision of the Network and its expansion to include additional disciplines was presented to the Chief Medical Officer. The Medical Visualisation Advisory Committee presented the future strategy focusing on the development of the first definitive dataset for the 3D, interactive digital human for anatomical education, training and simulation.

3. Context

At the time the Feasibility Study was proposed, various reports and studies at national level revealed a gap in the knowledge base that pointed to the need for increased research activities in the field of medical visualisation for research, training and educational purposes. These reports and studies are summarised below together with key assumptions that formed the general context in which this study was conducted.

The review of Basic Medical Education in Scotland (Calman Report), June 2004, recognised that the funding of medical education research is problematic, and noted that medical education does not feature explicitly in the Funding Councils' Research Assessment Exercise. The review added that clinical skills training is of fundamental importance to medical students and supported the need to teach medical students specific clinical skills within a non-threatening environment, away from the pressures and anxieties of actual patient contact. The review emphasised the need for research in medical education and went on to recommend the creation of a Centre for Basic Medical Education that would encourage collaboration and new uses of technology.

Higher Education in Scotland: A Baseline Report, July 2004, analysed the data from the 2001 Research Assessment Exercise and reported that whilst there was a strong Scottish research base in generically biological or medical science based subject areas, there remained developmental opportunities in nursing and other studies and professions allied to medicine. The Scottish Higher Education Funding Council recognised the need for improving research in nursing and health by funding HealthQWest, which was launched in 2005. HealthQWest has identified its key priority themes as Decision Making, Function for Living and Gerontology. (None of these areas overlap with the key research areas identified in this study which focused more on the education of health professionals)

A Framework for Higher Education in Scotland: Higher Education Review Phase 2, (2003), recognised that the most exciting breakthroughs in research in the next decade were expected to be at the boundaries between disciplines, across the sciences, arts and humanities and that the funding system should encourage exploration at these boundaries. This study has operated across medical disciplines and through the extended field of visualisation that encompasses areas of computer science and human computer interaction as well as design, psychology and visual communication. It has explored new avenues of research that have the potential to contribute to Scotland's economic and social wellbeing.

Since the start of the Feasibility Study, an updated literature review (Appendix 12.3) has uncovered further background information that contributed to the project. Medical visualisation has been an active area of research worldwide over the last two decades. Only recently, however, has technology reached a level of maturity and cost/performance ratio that makes its deployment feasible on a large scale. In addition to providing scope to explore research in medical education and practice, this opens a window of opportunity for near-market research and product development that combines the underlying core technology with user-led know-how to deliver the solutions that today's market demands.

It is recognised that undergraduate anatomical training has been limited in recent years as the availability of cadavers for undergraduate training has significantly declined. Additionally, increasing student numbers and pressures from an expanding undergraduate curriculum has resulted in a reduction of students' exposure to cadaveric material and in total anatomical teaching time (Turney, 2007).

Supplementary teaching tools that involve book related material and PowerPoint presentations can also be perceived as unsatisfactory by medical students who experience significant difficulties perceiving three-dimensional information through two-dimensional means (i.e. diagrams and screen presentations). Although cadavers could be considered as a three-dimensional teaching tool, they offer very limited interactivity. Nor do they offer the repeatability that is required for the assimilation of knowledge regarding specific sections of the human body and complicated surgical techniques. Hence a student does not have the luxury to repeat specific dissections at his/her own pace and time in order to understand anatomical structures.

Additionally, many students are unable to mentally map and reconstruct 2D information derived from diagrams into a 3D context. Noticing these limitations, a number of studies have tried to replicate specific anatomy lectures through physical simulators. Although these may represent a first step to a more informative and stylised supplementary method of teaching anatomy they can be unrealistic and unsatisfactory for teaching more complicated structures.

Research has also suggested that medical and surgical trainees require anatomical resources that are convenient and adaptable to the desired educational content and techniques (Pandey et al., 2007; Ward et al., 2008). This observation was also supported by hospitals and medical schools across the UK highlighting the need for more approachable, simple and long-lasting training methods.

As a response to these requirements, some research studies have focused on the development of VR learning material. Initial results of comparative studies between traditional and structured VR training illustrated a significant shortening of the trainees' learning curves (Sang-Hack et al., 2006). Investigations involving similar medical visualisation techniques have also suggested that synthetic training environments are becoming an increasingly viable alternative to traditional cadaver anatomy training (Crossan et. al., 2002).

During their training period, medical students must develop a wide range of competencies including the acquisition of information and knowledge (e.g. anatomy), technical skills (e.g. laparascopic surgery), diagnostic skills (e.g. physiology) and 'practice' skills (e.g. collaborative working, and working with patients). Increasingly, these areas are taught in a complex environment with less tolerance for error. Computer based simulation offers the potential of an environment in which students can learn and practice skills without endangering patients and in which limited resources can be maximised.

Simulation offers significant advantages in learning and planning especially for rare, dangerous, and complicated procedures. With the integration of scan and other digital data, it offers the ability to plan surgical procedures using patient-specific information.

Computer graphics and machine vision laboratories both in the UK and abroad are already focusing efforts on this type of simulation as well as image generation for medical applications. Generally, they focus on the algorithmic issues for simulation, data extraction and representation, for example, the Computer Vision and Graphics Research Group at Glasgow University which develops methods for acquiring 3D surface topology for facial reconstruction.

Other research groups focus on particular aspects of clinical application, for example the collaboration between Medical Physics and the Institute for Materials and Processes at Edinburgh University to model blood flow though arteries; or the desktop system developed by Rutgers University, America for rehabilitating hand function in stroke patients.

Few of the resulting research outputs are integrated into clinical or teaching practice. This apparent disconnect arises partly from the early stages of development (from limitations of processing power and cost), and partly from the lack of an established route from patient-specific data to clinical application.

Against these issues, this Feasibility Study formed the view at the outset that it should focus on application and interaction, adapting advanced visualisation algorithms, toolsets and techniques where these would have direct impact on the needs of medical practitioners.

4. Original Aims & Objectives

An aim and a series of objectives were proposed to the Scottish Funding Council as part of the submission for funding. As they remained central to this Study, they are reiterated below.

Aim
The aim of the Feasibility Study is to bring together key individuals from medical schools, medical practice, Higher Education Institutes and other relevant organisations to identify future areas of research that address 3D digital visualisation and interaction and its impact in medical contexts. In particular, these contexts include risk reduction, real-time planning and surgical rehearsal, safer patient care, innovative undergraduate and postgraduate education, cost effectiveness and a better understanding of healthcare in general.

Objectives
This Feasibility Study sets out to:

- Establish a network of academics, clinicians, practitioners, medical and technical visualisation specialists, and basic scientists to identify the appropriate use of real-time 3D imaging and interaction to promote innovative and intuitive teaching and training methodologies.

- Identify areas where real-time 3D digital visualisation technologies can support education and training, including present and future clinical diagnosis and surgical rehearsal.

- Explore situations where 3D digital anatomical toolsets and models can be used by students and practitioners to repeatedly explore and diagnose, in order to augment and supplement cadaver-based practice

- Devise strategies where 3D visualisation can play a role in patient understanding and recovery, and the promotion of good health and well-being.

- Recommend on the strategic deployment of 3D visualisation with regard to the infrastructure model, clinical and pedagogical principles, and roadmap to practice. This will include forming appropriate partnerships and seeking funding streams to support research and commercial exploitation of resultant intellectual property.

These objectives will be achieved through the establishment of a steering group; a review of research within the field; the establishment and growth of a contact dataset; provision of two workshops; and identification of champions to represent specific areas of future research.

The Report of the findings of the Feasibility Study should include:

- A review of worldwide activities in medical visualisation and simulation in relation to professional education and clinical practice.

- Identification of the key areas of research in which future Scottish and UK initiatives could engage, including those areas where the health sector is active and where the introduction of state-of-the-art 3D visualisation promises the greatest immediate benefit.

- Recommendations on the best way to deliver subsequently identified needs. These will include the pedagogical, clinical, technological and future research development infrastructure required.

- A fully-costed plan for the next stage of this initiative.

5. Methodology

The Methodology through which the business of this Study was conducted was formulated by Professor Paul Anderson at the Digital Design Studio and Professor David Rowley of the Royal College of Surgeons. It was agreed that the formation of the Network was the first priority.

The Network
In creating the Network, it was agreed this should:

- Engage with a broad range of disciplines and working practices across the medical health sector.

- Investigate curriculum developments and challenges within medical teaching including major hurdles in the understanding of anatomical features, both in teaching and in diagnosis.

- Understand current imaging technologies within healthcare, such as CT imaging, XRays and MRI.

- Investigate gaps in knowledge and understanding within teaching, research and diagnosis.

- Gather together a broad range of specialised disciplines, especially where these disciplines do not normally interact and to identify territories and duplication.

- Ensure wide geographical representation from all parts of Scotland.

- Be 'neutral' in its outlook free of issue or political direction.

- Establish a series of live case studies to directly engage with anatomical and visualisation issues.

Board of Management
To coordinate the above, an Advisory Board was formed under the chairmanship of Professor Anderson. As reconstructed as the Medical Visualisation Advisory Committee, (May 2008) the Committee consists of :

Professor Paul Anderson, Digital Design Studio, Glasgow School of Art.
Professor David Rowley, Royal College of Surgeons.
Dr James Miller, Royal College of Physicians

and Surgeons of Glasgow.
Dr David Chanock, Consultant Radiologist, Ayr General Hospital.
Professor Philip Cachia, Postgraduate Dean, Ninewells Hospital, Dundee.
Mr Bill McKerrow, Consultant (Ear Nose & Throat), NHS Highland.
Professor Ian G Parkin, Applied Clinical Anatomy, University of Dundee.
Professor Bertie Wood, HM Inspector of Anatomy for Scotland.
Mr Gerry McGarry, Consultant (Ear, Nose and Throat), NHS Glasgow.
Dr Ben M Ward, Clinical Lecturer, University of Edinburgh.
Vivienne Blackhall, medical student, University of Glasgow.
Dr Vassilis Charissis, Researcher, Digital Design Studio, Glasgow School of Art.
Linda Brady, Network Coordinator, Digital Design Studio, Glasgow School of Art.

One of the first actions of the Committee was to name the network. It was agreed that the Scottish Medical Visualisation Network was appropriate.

The Network has grown to a current total of 160 members through invitation and latterly through a dedicated website. Once created, the Committee met on a monthly basis. This continues to be the case such is the significance of its momentum despite the end of the Study in January 2008.

Technical Issues

Technical issues were addressed through a series of targeted case studies which allowed themes associated with real-time 3D imaging and interaction to be explored in an anatomical context. This approach moved significantly away from the traditional world of 2D text and images to a fully interactive real-time 3D world, where data sets, anatomical structures and advanced imaging allowed interrogation and diagnosis to take place as viewed from both the practitioner and medical student standpoints.

To facilitate case studies, a world-wide review was conducted to locate the best possible 3D human data set. This was purchased from the Zygote Media Group. It was subsequently found to be inaccurate in part and missing in detail. Over the duration of the Study, this model has been systematically updated and improved and now probably exists as the most accurate and finely detailed model of its kind.

Workshops

In 2007 the Network met on two occasions through day-long workshops, the first on 29 May the second on 14 November. These workshops presented findings and practical demonstrations of 3D visualisation technology.

Location

Committee meetings, workshops and on-going research work were located at the Digital Design Studio. To inform the Network, a series of visits was also organised to various teaching hospitals and university departments throughout Scotland.

Dissemination

While the Committee used the vehicle of the Workshops to disseminate directly to practitioners, a website was formed to reach a wider audience. This website provides information for the public but also contains a members area where more detailed issues can be discussed.

The activities of the Network, in particular the Workshop of 14 November, attracted wide media attention in Scotland including a major news item on BBC Scotland as well as press and journal coverage.

6. Outcomes

This sections lists the tangible outcomes created by the Network including the Workshops and Case Studies.

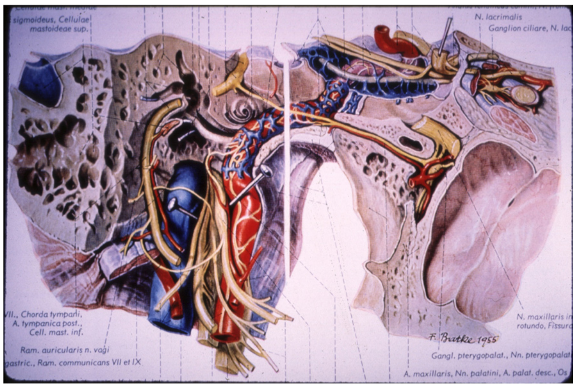
6.1 Workshops
First Workshop – 29 May 2007
The aim of the first medical visualisation workshop was to establish a dialogue with medical disciplines throughout Scotland. This workshop was developed in partnership with the Royal College of Surgeons, Edinburgh, and had two main objectives. The first of these was to introduce current research and teaching practice involving anatomical structures and how this would benefit from the development of real-time 3D interactive imaging. The second was to develop a series of demonstrations to act as focal points for discussion and debate that would inform future development themes for exploration within the Feasibility Study.

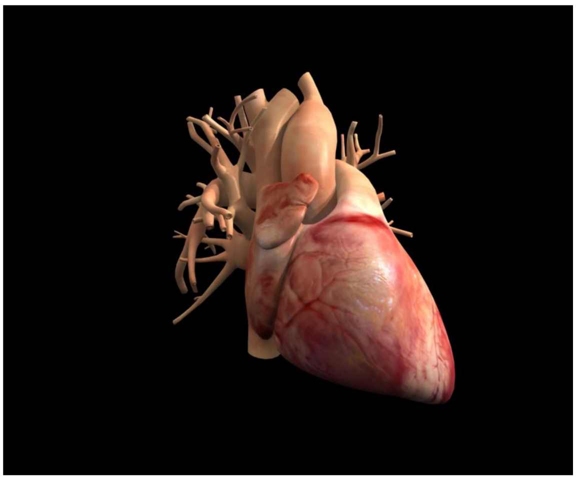
In addition to the two objectives above, the first workshop brought together a core group of Network members to assist in the identification and planning of future research themes in medical visualisation involving academics, medical practitioners, industrialists and visualisation experts. In forming this group, geographical representation covering all of Scotland was important as was ensuring that differing working practices and approaches were well represented. Consequently, delegates were invited from various regions ranging from the Highlands and Islands to the Borders as well as the Central Belt.

This workshop deliberately targeted a small number of delegates to allow a high level of interaction and involvement in the practical demonstrations and follow-on discussions. Although the target number for the workshop was small at 30+ delegates, a large range of disciplines were represented from medical teaching, anaesthesia, radiology, anatomy, surgery, urology and visualisation.

The group sought appropriate starting

Figure 1: 1st Workshop, 29 May 2007 - photographs and images from presentations (clockwise from top left): portion of cadaver; textbook illustration; presentation; discussion with workshop participants and 3D digital model of the heart.





points for case studies; identified challenges, determined an approaches to needs and learning outcomes. Speakers presented current practice in their fields and how use was made of advances in computer technology and visualisation techniques.

The workshop was also used as a technology showcase illustrating approaches taken in interactive 3D displays with content from other industries and disciplines. This was used to inform the workshop delegates of what was possible in other fields and what might be utilised within a medical context.

The group discussed the possibilities of 3D virtual reality and human-computer interfaces for resolving complex medical visualisation issues in the fields of surgical rehearsal, teaching anatomy, skills training, patient information and medical illustration.

Several themes were identified and prioritised as areas for multidisciplinary visualisation projects, five of which became case studies that were developed throughout the summer of 2007 and then presented in the second workshop.

The Workshop discussed means by which the Network could be established and decided that a multi-disciplinary Board should be formed.

See Appendix 12.4 for more information about this workshop.

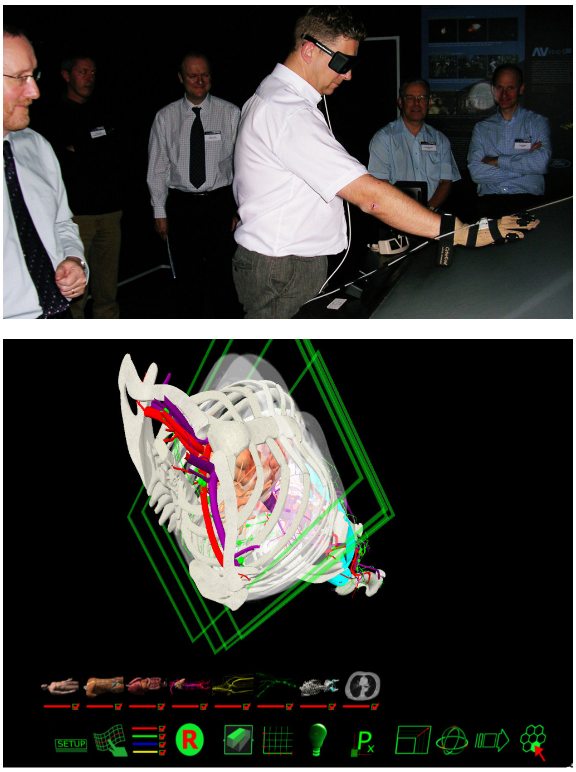
Between Workshops

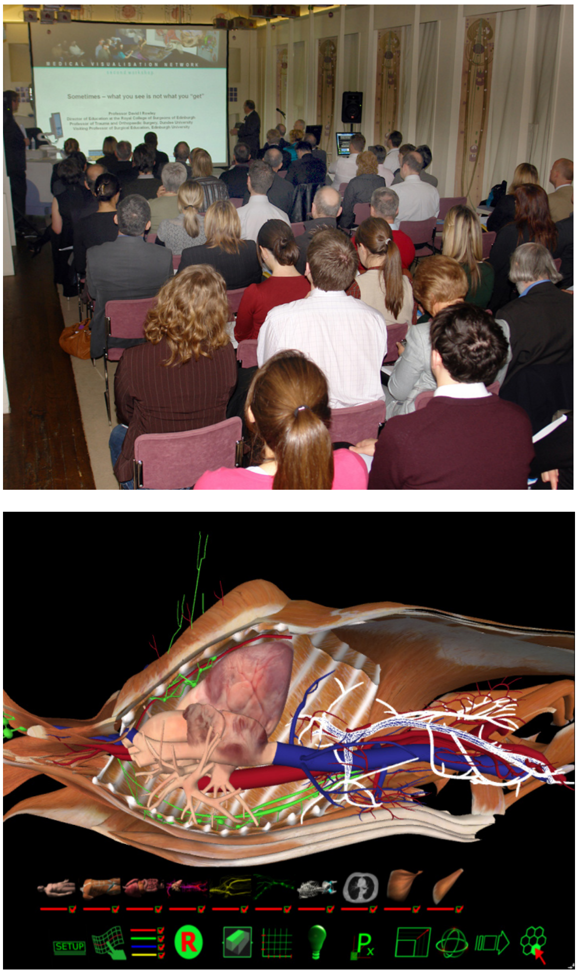
Following the first workshop, a Committee was established to guide and manage the 'Scottish Medical Visualisation Network'. The first meeting was held in June 2007, meeting on a monthly basis thereafter. Chaired by Professor Paul Anderson, the Board drew up a number of aims and objectives for the Network (distinct from the aims and objectives for the study as a whole) building on the discussions conducted at the first Workshop. It was also agreed that a website describing the work of the Network should be constructed.

Professor Philip Cachia from NES (National Health Education for Scotland) and ENT Consultant Mr Bill McKerrow of Raigmore Hospital, Inverness, joined the Board. The initial Committee of six has since expanded to its present compliment of 13.

The Network grew steadily to over one hundred by the end of the summer, 2007. As the Network expanded, case studies were identified

Figure 2: 2nd Workshop, 14 November 2007 - photographs and images from demonstrations (clockwise from top left): demonstration of the semi-immersive interaction tool for viewing 3D data; presentation to the audience; screenshot of the interaction tool with cross-section of the body; screenshot of the interaction tool, showing 2D layers of scan data superimposed on the skeleton and blood vessels.





and developed in the following areas:
• Breast Cancer
• Lung Collapse
• Foot and Ankle
• Lumbar Puncture
• Inguinal Canal
(see Section 6.2 Case Studies)

Second Workshop – 14 November 2007
The Second Workshop demonstrated the growth in numbers and excitement in general that the Study was generating. Seventy delegates attended from a total membership that now reached 120. Significantly, Richard Dimelow from the Scottish Government Health Quality and Safety, and HM Inspector of Anatomy, Professor Bertie Wood attended while the event was opened by the President of the Royal College of Surgeons of Edinburgh, Mr John Orr.

Professor Anderson described the Network's aims and objectives and introduced the Network's website. Professor Rowley, Director of Education at the Royal College of Surgeons of Edinburgh, emphasised the need for the Network and how it had a critical role to play in medical education.

Thereafter, the results of the case studies conducted by the Network were presented, including an interactive demonstration of a prototype haptic lumbar puncture simulator, introduced by Dr Jillian Hewitt-Gray of Ayr Hospital.

High quality 3D animations of lung collapse for teaching purposes were introduced by Dr David Chanock, also of Ayr Hospital, and a live demonstration of an ultrasound investigation of the foot and ankle was carried out during which the data produced was compared with virtual demonstrations and visualisations to improve the quality of teaching for radiologists.

After a networking lunch, attendees had the choice of visiting two of four demonstration-cum-discussion groups: the haptic lumbar puncture, the 3D heart, the virtual human body and the semi-immersive interaction tool for viewing 3D data.

For this workshop, medical students were introduced to the Study, first as user groups for the case studies, and then, as members of the Network itself. The students were enthusiastic about how 3D visualisation could help them with their studies and arranged to meet with Professor Anderson at a later date to find out how they could contribute to the Network as a group in their own right. Several radiologists requested certificates of attendance as part of their continuing personal development programme.

The event received substantial press for which Professor Bertie Wood provided the following quote for the Herald; 'What I saw today has unbelievable potential for medical education and surgical training'. See Appendix 12.5 for more information about this workshop.

Impact of the Workshops
While the second workshop was the last within the period of the Study which ended in January 2008, the Network continues to flourish. The workshops succeeded in providing a focus for discussion as well as a venue for networking by like-minded professionals from a wide range of disciplines. Membership was increased, sub-groups were formed and ideas for further research presented. There was a general consensus that, as a minimum, an annual event following the pattern of the workshops should be held.

At the time of writing, May 2008, membership of the Network has grown to 160. Medical students were identified as a sub-group of the Network. This group will be encouraged to grow and have their say within the Network as one of the main user groups. Plans are in place to establish a separate student area on the website. A student representative joined the Network Board in February 2008.

Scottish Medical Illustrators have organised an event in June 2008 to establish themselves as a stakeholder group and have invited the Committee to present the activities of the Network at the next Institute of Medical Illustrators' Conference in Durham in September 2008.

HM Inspector of Anatomy for Scotland, Professor Bertie Wood agreed to join the Network Board. He is an experienced administrator and medical educationalist, and his political awareness will assist the Committee in setting its strategic context. Dr James Miller, Chief Executive of the Royal College of Physicians and Surgeons of Glasgow has also joined.

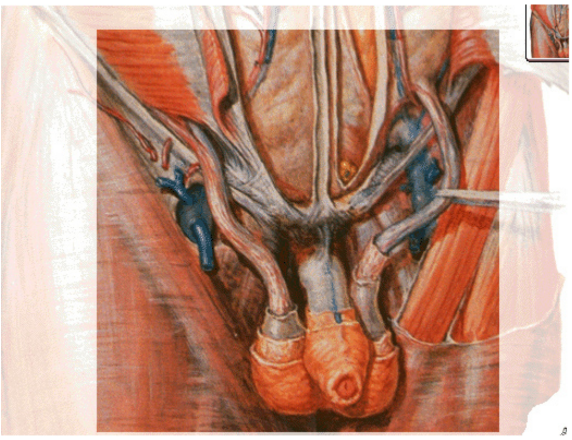
Further funded research projects are currently being focused on anatomy for chest drain simulation, the anal-rectal junction and the anatomy of the shoulder. These and other activities are outlined in Section 9.1.

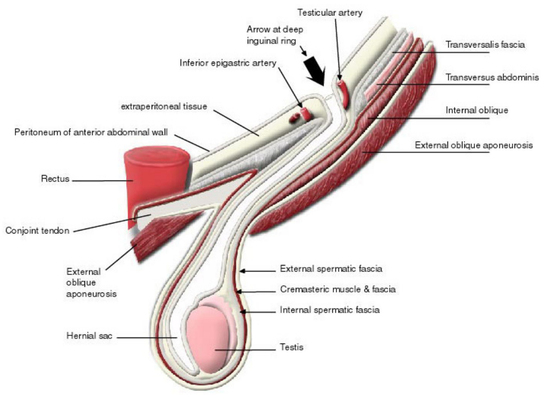
Media awareness of the Network continued to grow resulting in articles in the press and internet, interviews on radio and a feature in BBC Scotland's News programme. These are detailed in Section 7.4.

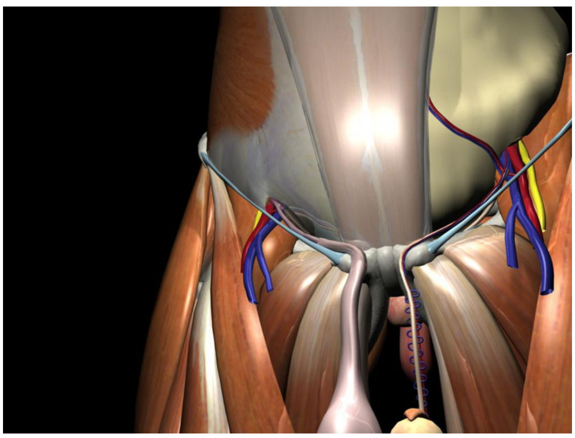
6.2 Research Case Studies

The five case studies previously referred to used a variety of 3D models, animation, 3D visualisation, haptic interaction, and live scanning to examine and explore the feasibility of using such techniques in surgical rehearsal and procedure, radiological training and educational validation. A user-orientated approach was adopted using technical resources and expertise which the Network facilitated, principally, medical practitioners working with experts in 3D representation, programming and the human-computer interface.

Figure 3: Teaching the Inguinal Canal (from top down): simple 2D diagram; more detailed 2D illustration; image from the newly built 3D digital model.







The studies explore interface, content and application. They attempt to illuminate the breadth of applications within medical training at undergraduate and postgraduate levels and across disciplines. Most notably, all the case studies have been peer reviewed and published at major International and British conferences.

Each of the case studies is presented below, describing the motivation behind the study, the methods used (including empirical investigations where appropriate), and the potential impact of the project.

Case Study 1 - The Inguinal Canal

Many surgeons have suffered long hours of doubt about whether they will be surgeons or not because they lack an understanding of the underlying anatomy of the inguinal canal. The Network developed an interactive 3D model which demonstrates this complex anatomy in a format that demystifies the complexities, allowing interactive inspection of the canal as each layer of visual information is added.

In the male the inguinal canal is the route by which the vas deferens and testicular neurovascular bundle pass through the musculature of the anterior abdominal wall. Although functionally less significant in the female it is, in both sexes, an area of potential weakness. It is possible to develop three types of hernia in, or close to the inguinal region: direct inguinal; indirect inguinal; femoral.

It is essential that all doctors, and particularly surgeons, know and understand the anatomy of the region to facilitate accurate diagnosis, appropriate treatment and safe, effective surgical repair. It would be beneficial if patients also had a better understanding of the normal anatomy underlying their condition.

Current methods for learning about this region are unsatisfactory, and medical educators struggle to teach this complex area. It is extremely difficult to reveal the three-dimensional relationships of the walls of the canal, its openings and its contents by cadaveric dissection, leaving digital reconstruction as the only feasible method of promoting learning and understanding. Existing digital data on the inguinal region is inaccurate and incomplete.

This project took the most complete and refined 3D model available on the market, then manipulated and augmented it to produce a complete and accurate representation of the inguinal canal. The end result was a beautifully detailed 3D model of the inguinal canal area.

Each opening (the deep and superficial inguinal rings) was now visible and seen to be "protected" by two of the muscle layers. The muscles and their aponeuroses were clearly defined and two of them (internal oblique and transversus abdominis) could be seen arching over the canal to form its roof and then its posterior wall (conjoint tendon).

Nearby relations, fascial layers, and important surgical landmarks were also made clear. The complex anatomy was beautifully revealed to promote not only learning, but also full understanding of the region, as interaction with the model meant the area could be viewed from all angles. The result will be incredibly helpful to those learning about the inguinal canal for the first time, and also to those learning how to operate in the region.

The package must be further developed into one that is easily accessible to staff and to students (undergraduate, postgraduate, patient) in an interactive framework that may be used at levels and speeds appropriate to the individual. The addition of pathology would be extremely helpful, showing reconstructions of the different hernia types and their consequences.

Other anatomical regions are equally complex and difficult to reveal by dissection. Education in anatomy could be supported and enhanced by similar packages covering embryological development, the peritoneal cavity, laryngeal function, and movements of the eye, to name but a few.

Case Study 2 - Applied Surgical Anatomy in Malignant Breast Disease

This case study developed a 3D interactive surgical model of the human breast and axilla (armpit) with lymphatic drainage, with emphasis on the surgical landmarks for axillary clearance. This area has complex spatial anatomy, and understanding the anatomy is essential to understand the disease process and its management. Working in a collaborative fashion an extremely high fidelity rotational model was developed.

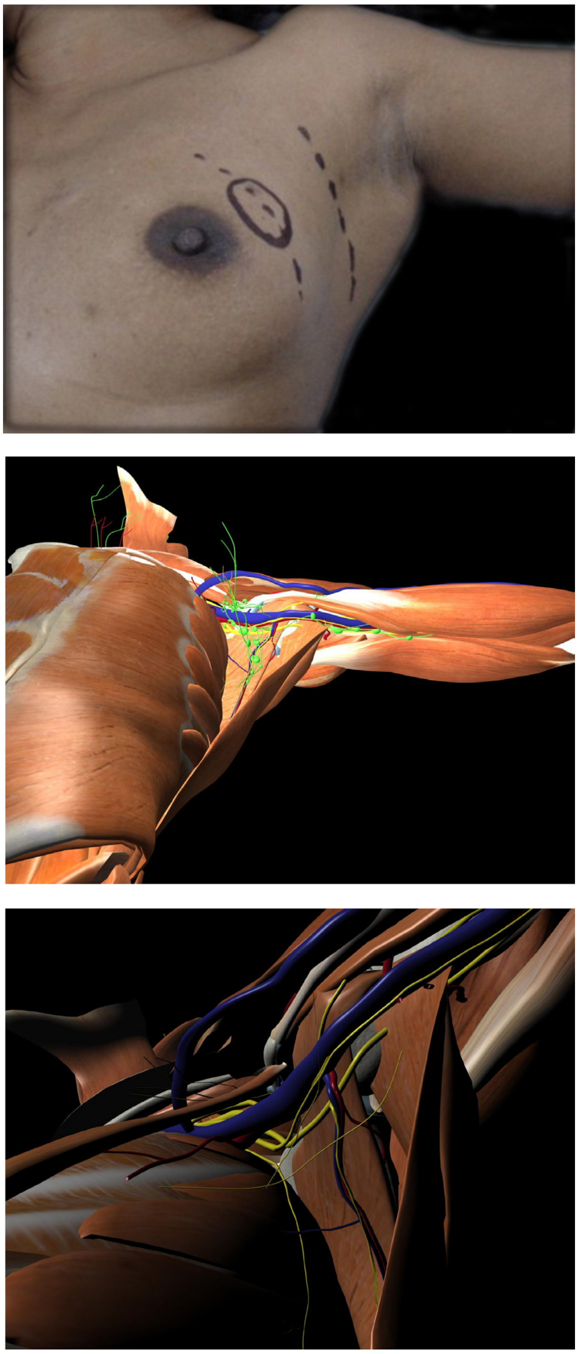
The model was presented in a semi-immersive display environment with an intuitive interface that would allow trainers and trainees to manipulate the true 3D model directly, reducing the steepness of the learning curve. Research studies focused on enhanced visualisation, haptic interaction and human computer interfaces.

By blueprinting learning objectives directly from the Royal College of Surgeons Membership examination (MRCS) a curriculum was created to teach the subject using an activity based approach in which the semi-immersive 3D learning environment was used to augment small group tutorials.

A series of trials were conducted exploring experimental questions on attitudes, practical requirements and validation of methods, with very positive outcomes. Iterations of validation and development of the system improved learning outcomes by removing unnecessary barriers to learning.

The analysis of these trials with Foundation Year doctors from across Scotland offered an initial and encouraging view of the potential of this type of medical visualisation. The results from the trials offered a wealth of data that

Figure 4: Breast and Lymphatic Area top: photograph with area marked for surgery; 3D model showing axilla; 3D model of axilla (detail).



were further distilled and presented through a series of national and international publications. These trials are described below, illustrating the different aspects under investigation, and their routes of dissemination.

Case Study 2 Trial 1: An Enquiry into VR Interface Design for Medical Training

The problem of visualisation for medicine is multi-faceted, requiring a co-ordinated approach. A key component of any visualisation system is the development of an appropriate interface which allows the user to investigate the chosen content while avoiding a steep learning curve. Previous attempts in the use of VR for medical visualisation have struggled due to a lack of focus on the interface. By combining the educational approach with intuitive interfaces the user is freed to learn. As part of the initial case study, interface designs were developed specifically for medical training and tutorials.

This work was presented at IS&T/SPIE international conference of Electronic Imaging in San Jose (Silicon Valley) California, USA. SPIE (International Society for Optical Engineering) is a world wide organization which supports an interdisciplinary approach and promotes advancements to the science and application of light. Its research includes the design and development of technologies in medical imaging and next-generation displays. The publication was presented by Dr. Vassilis Charissis and attracted significant interest from the delegates, particularly in respect of the interactivity attributes of the system and its application.

V. Charissis, B.M. Ward, M. Naef, D. Rowley, P. Anderson and L. Brady (2008), 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.

Case Study 2 Trial 2: An Evaluation of Prototype VR Medical Training Environment: Applied Surgical Anatomy Training for Malignant Breast Disease

Further to the initial trial an experimental approach was developed to validate the virtual model hypothesis and to learn more about the role of interaction, educational approaches and interfaces. The validation method built on the literature and aimed to look directly at learning outcomes; it also illuminated the trainee's perception of efficiency, utility and engagement.

A stakeholder group of Foundation Year doctors from across Scotland provided subjects for the study. Twelve subjects were randomized into two groups. They were pre-assessed and undertook a structured tutorial. One group was taught using existing resources (2D images, plastic models, text-books) and the other using the VR augmented system. External factors were controlled, and each group was debriefed using Multiple Choice Questionnaires (MCQs) and qualitative methods.

The study was designed to discover if the complex knowledge associated with spatial anatomy was improved by the VR system. The results were positive, demonstrating an improvement in learning outcomes related to spatial relationships. The approach was also found to improve engagement and encourage contextual learning, which is suggested to be a very important factor in promoting the use of knowledge in the clinical setting.

The findings were presented by Dr. Ben Ward at Medicine Meets Virtual Reality (MMVR) 16 in Long Beach California. The presentation created interest in the simulation community, mainly due to the integrative and streamlined approach demonstrated by the study. The paper was published in Studies in Health Technology and Informatics 132, IOS Press.

B.M., Ward, V., Charissis, D., Rowley, P., Anderson, & L. Brady, (2008), 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).

Case Study 2 Trial 3: Can Virtual Anatomy Augment Postgraduate Anatomy Teaching?

This study was trainee centred and explored issues in current specialist anatomy teaching such as real-world provision, suitability, engagement and learning outcomes. The focus was on Foundation Year Doctors as they represent the recent output of Scottish Medical Schools. They are also a good reflection of the new generation of learners (i.e. those that have never studied without the internet, never known a world without video gaming).

The initial trial was conducted at the Digital Design Studio in Glasgow and involved a volunteer group of Foundation Year Doctors from across Scotland. The group was evaluated for their prior exposure to anatomical teaching and surveyed to explore their experiences of currently available resources. The students were exposed to interactions with targeted

Virtual Anatomical models in a specifically designed semi-immersive 3D educational environment.

The results were interesting as the junior doctors had expressed concerns that the crowded undergraduate curriculum had left them unprepared for specialist training and that their personal attempts to learn were hampered by a complete lack of accessibility of appropriate resources. They were excited and engaged by the virtual learning materials, but were most impressed by the potential for the ready and immediate access that it offered. They also responded positively to the accurate, interactive and accessible nature of the 3D resources.

The results of this case study were released at the Edinburgh School of Surgery Day, reflecting dissemination back into the Scottish medical and academic community. The study was peer reviewed and presented by Mr. Ben Ward at the conference in November 2007.

B.M. Ward, V. Charissis, D. Rowley, and P. Anderson, (2008), Surgical Education: applied Virtual Anatomy: Can Virtual Reality Augment Postgraduate Anatomy Teaching? in Proceedings of the Edinburgh School of Surgery Day Conference, Edinburgh, UK.

Case Study 2 Trial 4: Surgical VR Training Environments: An inquiry into the application and validation of Volumetric 3D anatomy tutorials for operative surgical training.

Building on the previous developments it was decided to look at how the system could be used to maximize learning outcomes from operative exposure in surgical trainees. By using the system prior to a theatre session it was assumed that there would be an improvement in learning outcomes. This would allow a trainee to learn the relevant anatomy in context, with true spatial cues directly before proceeding to theatre.

The system was modified to maximize the intuitive interface so it could be immediately used in the clinical NHS setting. The principle was that a trainee could explore the surgical approach with a mentor prior to theatre, fail safely, see and discuss pitfalls and explore the anatomy immediately surrounding the surgical incision (in a way not previously available) free from constraint.

In addition, this pilot study looked at the possibility of simplifying the system to make it easier to use, small, portable and robust enough to be implemented practically. The work was presented by Dr. Ben Ward at SARS (Society of Academic and Research Surgery) Annual Conference in Birmingham and published in the SARS Yearbook Page 45 (2008).

B.M. Ward, V. Charissis, I. Young, D. Rowley, and O.J. Garden, (2008), An Inquiry into the applications and Validation of Volumetric 3D Anatomy, in Proceedings of the SARS International Conference, Birmingham, UK.

Case Study 3 - Lumbar Puncture

A doctor performing a lumbar puncture has very few visual aids available. Instead, he or she must rely on a thorough knowledge of the anatomy, experience and the feeling of touch to guide the needle. Today, the procedure is taught by watching an experienced doctor performing the operation and with the help of physical dummies simulating the various tissue layers.

However, current teaching methods have various shortcomings. The sense of touch cannot be acquired by watching the procedure. While physical dummies provide a good approximation, the materials simulating the tissue layers need to be replaced after each successful try; otherwise the next student could simply follow the existing canal. The materials, however, are costly. Given the shortcomings of the existing teaching methods, a computer simulation of the procedure was considered highly desirable.

This project developed a software prototype to simulate the lumbar puncture procedure. A clear spatial understanding of the anatomy it provides is extremely important as the procedure must later be performed with minimal visual cues. The software consists of a 3D anatomical dataset, a visualisation module, and a haptic (touch) simulation using the Phantom Desktop force feedback device.

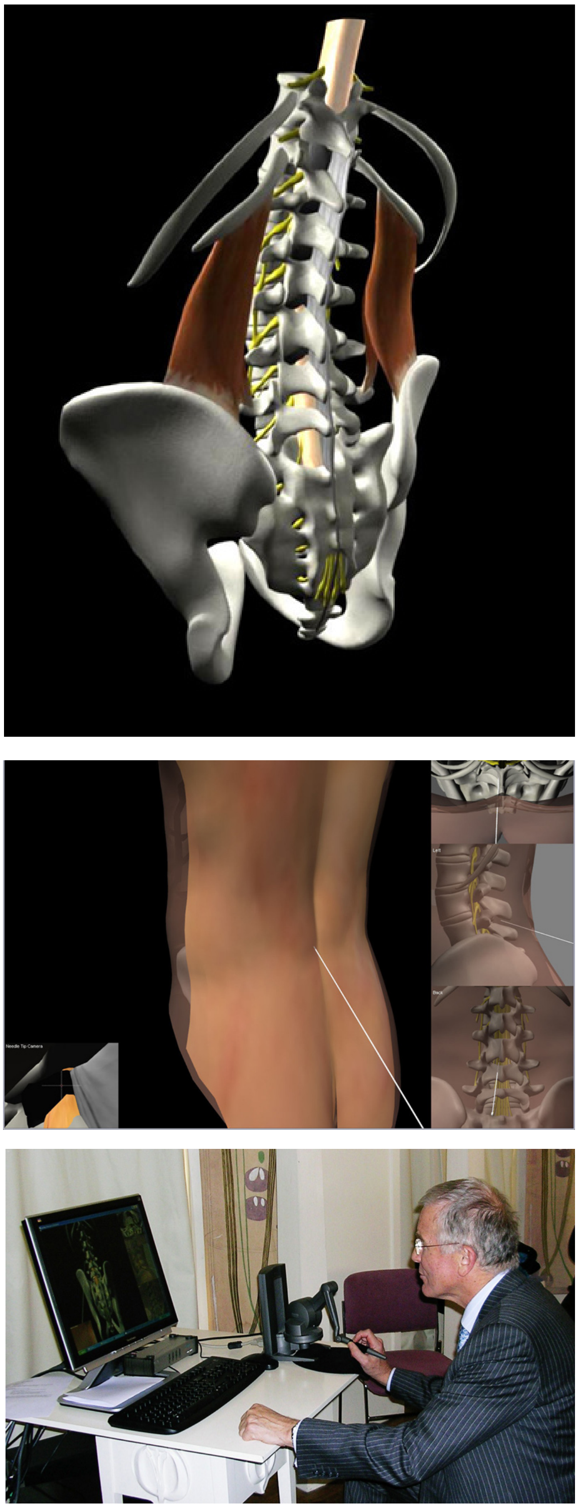
The dataset provides the base for both visual and haptic simulation, and covers the area of the back between pelvis and shoulders, including all the layers between the skin and the spinal canal; no internal organs are included.

The visualisation module includes three orthographic views (back, left and top) where only the bone and skin layers are enabled; these views are optimized to reduce visual clutter to effectively communicate the position of the needle relative to the spine. A large perspective view provides the most flexible visualisation; this view can be freely rotated and scaled using the mouse to look at various aspects of the local anatomy.

Individual tissue layers can be enabled, and a layer sequence is available to teach the order and spatial structure. A small view simulating a miniature camera attached to the tip of the needle provides additional spatial information while performing the procedure.

The user interacts with the application using the Phantom Desktop force feedback device.

Figure 5: Lumbar Puncture simulation (from top): the 3D model showing selected layers; screenshot of the visualisation tool showing different views and 'needle point' camera; the simulator in use by John Orr, President of The Royal College of Surgeons of Edinburgh, during the 2nd Scottish Medical Visualisation workshop.



The haptic simulation calculates the forces a surgeon would feel during the procedure depending on the needle position within the body. Additional interaction is provided using the keyboard to show or hide the individual layers and using the mouse to rotate the view.

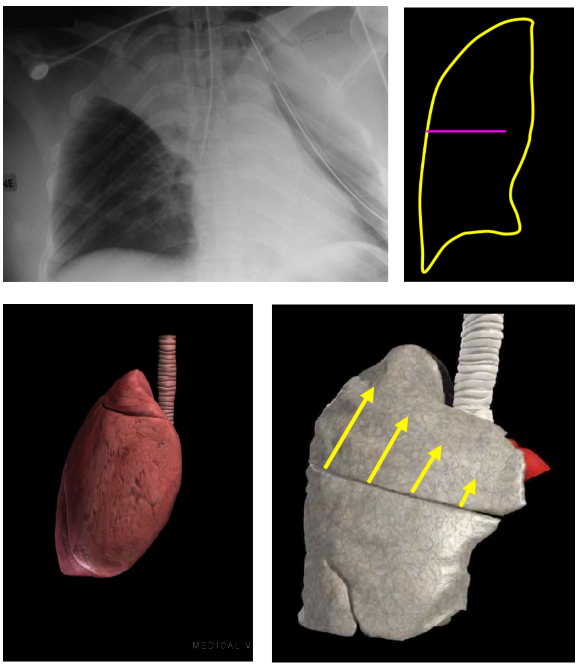
This project demonstrated the principle that a high-quality visualisation combined with haptic feedback can provide an exciting and powerful training tool for medical students. Future simulators developed from this prototype would improve the haptic simulation, the anatomy to provide a curved spine model, and a physical environment in which students performing a lumbar puncture can use their hands to feel the spine and provide a frame of reference to guide the needle relative to the patient.

The simulator developed as this case study requires relying on visual cues only, with an input device that is not visually related to the patient data in any way. Any future teaching tool must therefore integrate the force feedback device into a physical dummy to enable passive haptic feedback as a reference system.

Case Study 4 - Interpretation of Lung Collapse

Lungs collapse when a foreign body, infection or cancer obstructs one of the branches of the airway. Lung collapse is a notoriously difficult subject to teach as it requires a 4D understanding of anatomy i.e. a 3D spatial understanding of the region in a healthy state,

Figure 6: Lung Collapse (clockwise from top left): X-ray; simple 2D diagram; more detailed graphic illustration; screenshot from 3D animation of lung collapse.



and an understanding of the mechanisms of collapse in disease states. This case study looked specifically at research into the interpretation of CT/plain x-ray images of the chest in lung collapse. Interpreting 2D plain films of the chest demonstrating lobar collapses can be quite challenging; teaching their interpretation is even more difficult.

Using the methodology developed for the study on breast disease described above, the lungs and viscera of the chest were modelled under guidance from a consultant radiologist. This model was fully interactive in real-time, including the collapse of the lungs. By experimenting with computer simulations of volume loss, and utilising CT/MRI and plain film data alongside medical expertise, the model was developed to demonstrate in real time the process of each of the lobes collapsing. This was then linked to CT and plain film secondary images of collapse.

The system was designed to facilitate a 3D understanding of the process and integrate this understanding with the 2D imaging modalities. This application had the specific objective of integrating the teaching of specialist 3D anatomy with clinical procedure and image interpretation. Notably the system was designed to synchronously augment current clinical training or to be self-led and asynchronous. It was designed to convey the anatomy to a multi-disciplinary audience. The approach capitalised on current educational theory and enhances the current approaches by utilising advanced visualisation with an emphasis on practical and intuitive interfaces.

The model was presented at the second workshop and also as a lecture to 4th Year medical students at Glasgow University attracting encouraging feedback. The model and results will also be presented in Birmingham at the UK Radiological Congress 2008 by Mr. Ben Ward and Dr. David Chanock.

B.M. Ward, D. Chanock, V. Charissis, P. Anderson and L. Brady (2008), Interpreting Lung Collapse: A Randomised Controlled Study into the Impact of Three-Dimensional Animation, in Proceedings of the United Kingdom Radiological Congress (UKRC 2008), Birmingham, UK.

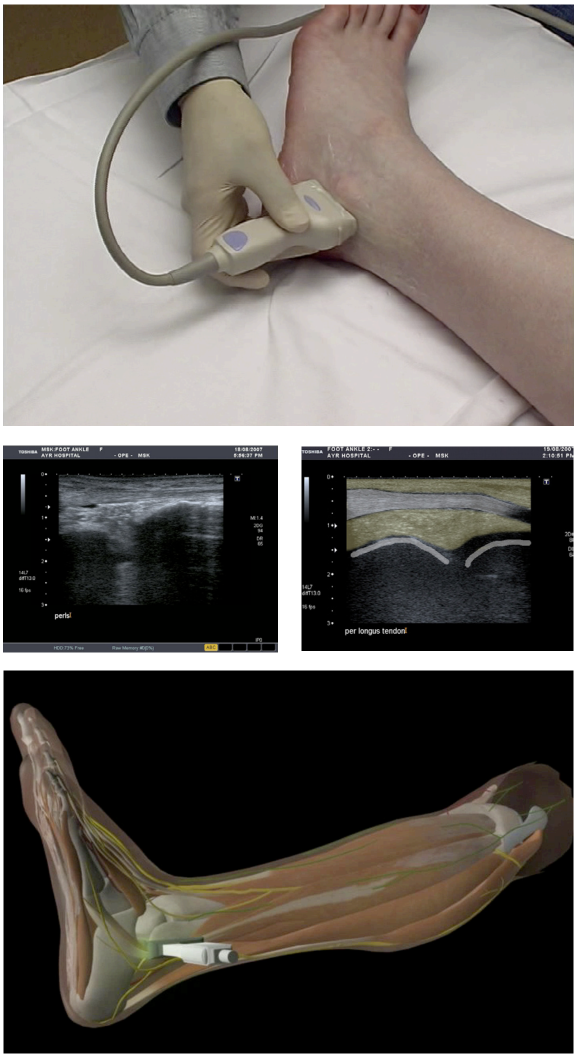
Case Study 5 - Musculoskeletal Ultrasound Training

This research project investigated methods of teaching practical imaging skills in tandem with applied anatomy, and was presented at the 2007 British Society of Rheumatology Foot and Ankle Course. Currently trainers are concerned that trainees are ill-equipped for specialist training and are forced to teach applied anatomy alongside practical skills in a clinical setting.

Ways in which users can improve their learning outcomes by the use of multiple sources of data in combination is currently of interest internationally. This study looked at the impact of interactive 3D models of the foot, ankle and lower leg when teaching musculoskeletal ultra-sound. Real time scanning with an actor and trainee was combined with real ultra sound images with a 4D animation of the structures over which the probe was passed. Hence students were able to collate complex procedural techniques alongside clear anatomical reference and interpretation of images.

In particular, a visualisation methodology was employed that allowed real time interlinking between a low latency rotational 3D anatomical model, visual descriptors of

Figure 7: Foot and Ankle (from top): scanning the ankle; ultrasound image; ultrasound scan with different tissues delimited; still from 3D animation of scan.



ultrasound technique (positioning, movement, field) and clinical ultrasound images. This teaching strategy linked the image directly to the anatomical structures and facilitated the learning of the procedure immediately in the way an expert uses the knowledge. This is the first example of this strand of research, and shows great potential for further development. As with other strands of this work the novel approaches have applications across medical practice and beyond.

This particular 3D model was developed as an explanatory tool, for complementing contemporary musculoskeletal ultrasound training. Initial trials suggested that the 3D representation of the procedure in conjunction to 2D data could be significantly useful as a training method. This is compounded when procedural techniques and specialist anatomy are effectively taught simultaneously. The model was presented at the second workshop in November 2007 and also as a lecture to 3rd Year medical students at Glasgow University with great success.

The next stage in this process is to validate the model using radiology trainees. This project is currently in progress in the West of Scotland deanery. Robust validation methods will be used to explore this interactive 4D approach to learning complex medical disease processes. The model and results will be presented in Birmingham at the UK Radiological Congress 2008, by Dr. David Chanock. The UKRC is a multidisciplinary Congress covering all aspects of diagnostic imaging and oncology, as well as radiology informatics and service delivery.

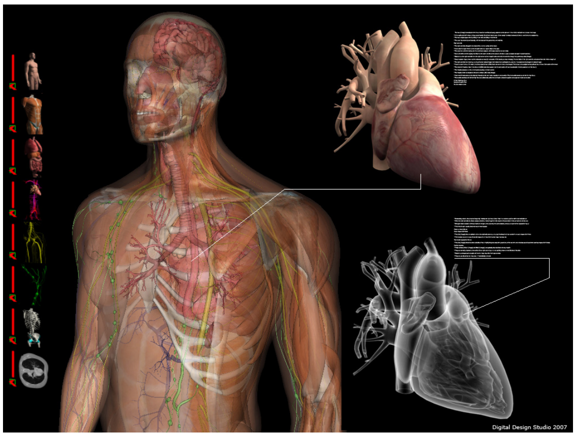
D. Chanock, V. Charissis, B.M. Ward, L. Brady, and P. Anderson (2008), Enhanced 3D Visualisation: Augmenting Musculoskeletal Ultrasound Training, in Proceedings of the United Kingdom Radiological Congress (UKRC 2008), Birmingham, UK.

Case Study Tools and Technologies

The technical implementation of the case studies was based upon a unified high-end visualisation technology platform that is used in various projects at the Digital Design Studio. This platform is a combination of commercially available development, content creation tools and custom software developed in-house by the DDS. Content creation refers to the process of creating the 3D models. All anatomical 3D data sets for the individual case studies were based on a commercially available male human 3D model purchased from Zygote. This data set is currently the most complete and refined 3D model available on the market, and was therefore chosen as the starting point. However, after consulting with various anatomists within the network, it was discovered that some of the data was inaccurate and a significant amount of detail was missing; this had to be added for the case studies.

The models were updated and built using Maya 8.0, a state-of-the-art 3D modelling tool with a particular strength on free-form surfacing. Unlike volumetric models as provided by CT or MRI scanning techniques or other methods (e.g. the Visible Human dataset), these 3D surface models are immediately suitable for real-time rendering and interaction and can easily be “stylized” to support teaching.

Figure 8: The 3D anatomical model (from top): female and male datasets; more detailed views of the model.

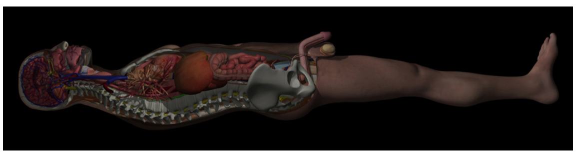


3D off-line rendering was also done in Maya in order to create the video materials required for the "Foot and Ankle" and the "Lung Collapse" case studies. Real-time rendering and interaction was implemented using custom software based on the Multigen-Paradigm VEGA Prime visualisation toolkit. VEGA Prime represents the current state of the art for visual simulation software. The "Breast Cancer" study also used the AutoEval software environment developed at DDS. The newly developed datasets and software were presented using a range of display and interaction environments. The "Lumbar Puncture" study used a desktop display system augmented with a high-precision force-feedback input device, the Phantom Desktop.

The "Breast Cancer" study used AutoEval, the Digital Design Studio's most advanced 3D interaction system comprising a Fakespace Workbench semi-immersive projection system with 3D tracking and tactile feedback on a data-glove for immersive interaction with the model.

Figure 9: The AutoEval 3D interaction system (from top); a surgical trainee examining the breast area; screenshot showing the interface.

Figure 10: View of high resolution 3D model available using the wide screen display.



All data sets can be displayed in real-time on other display systems at the DDS, including a high-resolution wide-screen solution which also provides an alternative configuration for passive-stereo viewing, (for the highest visual quality), and an active stereoscopic wall-display for increased spatial understanding and simple navigation using a robust game-pad.

All development work was conducted in close collaboration with medical professionals from the fields of radiology, surgery, and anatomical teaching to ensure precision and relevance of the applications and data sets.

7 Dissemination

Dissemination of the activities and ouputs of the Network has been wide and varied, including academic, professional and public audiences:

7.1 Website

The Scottish Medical Visualisation Network website www.medicalvisualisation.co.uk is the main vehicle for keeping Network members up to date with news, projects, events and publications. It was upgraded in February 2008 to include a members' area to disseminate news, published papers, research material and animations and presentations from Network events.

Although not envisaged at the start of the Study, the website is an invaluable tool for dissemination. Whilst it started as a simple information source about the Network in general, it is now security protected and its structure under development by the members. The cost of the website is being met by the DDS and the RCS.

7.2 Peer-reviewed Publications

The five case studies detailed in section 6.2 have resulted in eight publications, which are presented in Appendix 12.2.

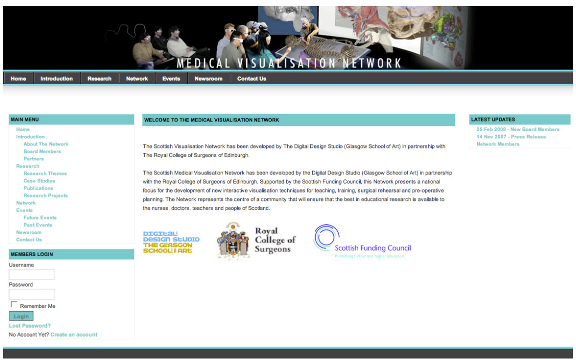
7.3 Press and Media

The establishment and work of the Network has attracted significant media attention, leading to printed articles in press and a range of interview and news features in both radio and television.

Articles in the Press

- "Virtual Patients for Surgery Practice". medGadget, Internet Journal of Emerging Medical Technologies, January 2, 2008.
- "Surgeons taught in a virtual world". (In feature, "Scotland Claims Two Medical Breakthroughs".) James Morgan, The Herald. Thursday 15 November 2007.
- "Now docs can walk 'inside' you". John McCann, Evening Times. Thursday 15 November 2007
- "Video Special: Now docs can walk 'inside' you" John McCann, Evening Times Online. Thursday 15 November 2007 (Includes video clip) www.eveningtimes.co.uk/news/display.var.1834562.0.0.php?act=login
- "A View from Tomorrow's World… Today" Metro. Tuesday 23 October 2007
- "Hi-tech lab gives a 3D view of our innermost secrets…" Ross McKinnon, Evening Times. Monday October 22 2007

Figure 11: Screenshot of home page, Scottish Medical Visualisation Network web site.



Television

- "Virtual bodies aid surgery skills" BBC Scotland News, Wednesday 2 January 2008 http://news.bbc.co.uk/1/hi/scotland/7167856

Radio

- Interview with Professor Paul Anderson (Director, Digital Design Studio) for Radio Scotland's Newsdrive programme, 15th November 2007.
- An interview with Professor David Rowley (Director of Education, Royal College of Surgeons of Edinburgh) for Radio Scotland's Good Morning Scotland programme; 15th November 2007
- Radio 5 Live. Live interview with Professor Paul Anderson. Broadcast Wednesday 2nd January 2008
- Good Morning Wales. Live interview with Professor Paul Anderson. Broadcast Wednesday 2nd January 2008

Other Websites

News items were reflected on the respective web-pages and attracted further international attention.

http://news.bbc.co.uk/1/hi/scotland/7167856

http://www.newspeida.eu/news/11494/virtual+bodies+aid+surgery+skills

http://24hnews.net/Health/Virtual-bodies-aid-surgery-skills.html

http://www.iran-daily.com/1386/3034/html/science.htm

http://medgadget.com/archives/surgery

http://hospitalnewswatch.com/aggregator?page=22

8 Financial Statement

8.1 Budget granted by SFC
The sum of £97,105 was originally requested from the SFC. However a 10% reduction was requested which resulted in the sum of £89,722 being granted for the one year Feasibility Study based on the following costs (See Table 1):

The costs included a full-time researcher, the services of the Director of the DDS, travel costs and the expenditure required to run two workshops:

- Researcher: the duties of this position included administrative support to the Network and Committee (including arranging the workshops) in addition to research activities.
- Travel costs: these included a budget for the PI and Researcher to travel to university and NHS research centres to conduct interviews with researchers and practitioners, and to survey ongoing research activity.
- Workshop costs: these covered room hire, catering, travel and subsistence costs for attendees, the Committee and Researcher, as well as the preparation of materials for dissemination. The costs were estimated on the basis of 30 persons attending each workshop.

8.2. Actual Income and Expenditure
During the period of the Study, the initial grant from the SFC was supplemented by cash contributions from the Royal College of Surgeons and Ayr Hospital to give a total income of £94,897 (See Table 3). Total expenditure was £100,504 representing an overspend of £5,645 or 5.95% to the period end (See Table 2).

Directly Incurred Costs
Salary costs for the Researcher at £33,363 were slightly less than the anticipated £36,601. Travel costs were also less than anticipated. The Committee agreed to meet on a monthly basis at the DDS and covered their own travel costs. However, other direct costs were much higher than anticipated.

It became clear after the first workshop that additional money would be required to develop the case studies. In particular, a 3D model of the human body was purchased along with appropriate software and licences. The RCS and Ayr Hospital contributed a total of £5,175 towards these additional costs.

Although the case studies were largely carried out by the DDS and members of the Committee, additional modelling expertise was bought in at a cost of £1,576 to allow completion of a specific case study before the date of the second workshop.

The success of the Network meant that the original estimate of 30 delegates for the second workshop was underestimated as numbers eventually rose to 70. Together with venue hire, printing and other sundry costs, expenses for the second workshop amounted to £6,640.

Directly Allocated and Indirect Costs
While costs were allocated as originally intended, after the first workshop in May 2007,

TABLE 1. Table of estimated costs (based on Full Economic Costing)

Item	Description	Cost
Directly Incurred Costs		
Researcher	Direct cost of a researcher for 12 months based on current salary bands. Includes superannuation and NI, but excludes inflation.	£36,601
Travel	Budget for travel to other universities and NHS research centres, and travel associated with Management Group activities.	£3,000
Other	Cost of organising and hosting 2 workshops. Includes VAT.	£3,000
Directly Allocated Costs		
Project Supervisor	Services of Professor Paul Anderson (average of 4 hrs/wk) to direct the Feasibility Study.	£8,458
Indirect costs		
Estates	Rates set by Institution; calculated on FTE	£7,985
Indirect	Rates set by Institution; calculated on FTE	£30,678
	Total Cost	£89,722

Professor Anderson substantially increased the amount of his time spent on the project.

Additional Costs
As the Network proved to be a success, it was decided to establish a website where members could be informed of the latest information, news and events. The cost for this was not anticipated in the original budget. This is being met by the DDS and the RCS. The amount spent so far (May 2008) on domain names, web set-up and staff training has been £2,623.

The case studies were presented at two international conferences in the USA. The cost of sending two researchers to these conferences was £3000. The total estimated additional costs therefore amounts to £5,623.

Post Feasibility Study Income
The Feasibility Study was completed in January 2008. However, the DDS, the RCS and the members of the Network are committed to the continuation and growth of the Network. To ensure continuity of personnel and activities, the RCS invested £30,000 immediately after the SFC funding ceased. In addition, funding has been secured from various other sources to carry out specific research projects for example NES and Raigmore Hospital, Inverness.

At time of writing, this income is estimated at £78,908. Full details of post-feasibility activities can be found in the Section 9.1.

TABLE 2. Table of expenditure for the Study

Item	Description	Cost
Directly Incurred Costs		
Researcher	Direct cost of a researcher for 12 months including superannuation and NI.	£33,363
Travel	Budget for travel to other universities and NHS research centres, and travel associated with Management Group activities.	£965
Other	Tools, technologies and software for case studies, 2 workshops.	£19,093
Directly Allocated Costs		
Project Supervisor	Services of Professor Paul Anderson (average of 4 hrs/wk) to direct the Feasibility Study.	£8,458
Indirect costs		
Estates	Rates set by Institution; calculated on FTE	£7,985
Indirect	Rates set by Institution; calculated on FTE	£30,678
	Total Expenditure	£100,542

TABLE 3. Table of income over the Study period
Expenditure

Income	
SFC Grant	£89,722
Other (RCSed, Ayr Hospital)	£5,175
Total Income	£94,897
Expenditure	£100,542
Overspend	£5,645

9 Continuing Research Activities

Although the period of the Feasibility Study is now complete, such is the momentum of the Network that activity remains at a high level. Funding has been secured for a number of projects which are underway, a series of funding applications is in preparation, and the first PhD studentship arising from the Network is due to start in the next academic year. The Network is also continuing to develop contacts with medical, academic and industrial organisations through one-to-one meetings, events and conferences. These research partners are listed in Appendix 12.6.

9.1 Current and Agreed Future Projects

Support for ongoing network activity

The Royal College of Surgeons of Edinburgh contributed £30,000 to support the continuing activity of the Network, particularly providing continuity of personnel, and the development of the web site.

The Anal-rectal Junction

Visualisation of the anal-rectal junction was funded by NES (NHS Education Scotland) at a cost of £7,508. There is a need for accurate 3D imaging of the anal-rectal junction, a very complex structure which is difficult to visualise and teach.

This project is creating an initial, detailed, 3D model comprising anatomy and structures of the anal-rectal junction which will allow students and practitioners to understand and comprehend the complex layers and structures of this region.

The foundation work associated in developing this model has huge potential to be used as an educational tool for visualising and enhancing the understanding of this complex structure. The outcomes resulting from this project will subsequently be used to develop a simulator for laparoscopic colorectal surgery, with the potential to put Scotland at the forefront of colorectal laparoscopic surgical training.

Similarly, this work will give surgeons better confidence in pre-operative planning of laparoscopic colorectal surgery. Project conclusions will form the basis of a larger future research programme focusing on building a haptic real-time simulator for laparoscopic colorectal surgery. The Skills Centres in Aberdeen and Dundee, together with the Scottish Clinical Simulation Centre in Stirling, have expressed an interest in this type of visualisation work.

Chest Drain Simulator

The Committee identified the need for accurate 3D imaging for the insertion of chest drains, particularly with reference to pneumo-thorax and pleural effusion. This procedure, which can have critical consequences if performed wrongly, is normally taught to Foundation Year 2 students using pig carcasses.

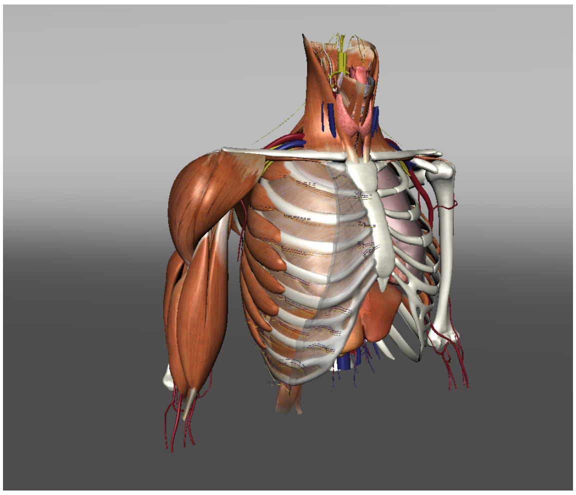
There is a requirement for a simulator that would allow students to practice the technique of inserting chest drains using the correct anatomy, while retaining the physical feedback received when inserting drains through skin and muscle. This haptic simulator will be accompanied by an animation demonstrating how the procedure should be carried out.

A three-week project valued at £6,400 has been funded by NES representing the first stage of the development of such a chest drain simulator, comprising the development of a detailed 3D digital model of the anatomy of the chest, lungs and thorax, and the animation demonstrating the correct procedure. It brings together visualisation and modelling experts with the very necessary medical diagnostic input of a leading clinician and anatomist.

This work has the potential to permit safer, less traumatic surgical procedures because of its ability in rehearsal using the correct anatomy. Further development of a new simulator will allow high degrees of repeatability in a training scenario without the need for consumables associated with current practise.

This simulator would allow students with no experience of the procedure to rehearse the insertion of chest drains with a greater understanding of the 3D human anatomy (not animal) and the penetration of underlying structures. This approach satisfies the need to produce repeatable training experiences for multiple student groups.

Figure 12: Chest Drain Simulator: 3D Anatomy.



3D Modelling of Shoulder Anatomy

Anatomy of the human shoulder is complex and multi-layered, making it a challenging area for traditional anatomical teaching and surgical training. This preliminary pilot study, funded by the Centre for Health Science in Inverness and valued at £10,000, is creating an anatomically accurate digital dataset of healthy shoulder anatomy, incorporating the multiple structural levels from bone, cartilage and ligament etc., out to the surface covering of skin. The dataset can then be manipulated, explored and tested using 3D VR equipment by a variety of target users, including students, physiotherapists, doctors, surgeons and radiologists.

Although relatively crude, '2.5D' illustrative resources are currently available, this project is an entirely new work, unprecedented in terms of its accuracy and true 3D VR capability. The shoulder region is a particularly appropriate study as the Inverness Group has collective expertise in the fields of shoulder physiotherapy, surgery and diagnostic imaging (CT, MRI and Ultrasonography).

After successful development of a tangible and demonstrable pilot system, there will be considerable scope to develop the model further, incorporating a range of realistic disease and injury characteristics commonly found in the shoulder. Arthritis, rotator cuff disease, fractures and dislocations are pathological conditions eminently suitable for 3D VR modelling.

Practical applications could include teaching of medical students and theatre personnel, training of physiotherapists and GPs in injection techniques, rehearsal of shoulder operations, development of joint prostheses and fracture fixation devices.

Documentary Film on Mediaeval Medicine

This project, funded by Wild Dream Productions and valued at £5,000, is for a series being made for the History Channel about mediaeval medicine. In 1403, Prince Hal, later Henry V, received a grievous injury when an arrow penetrated and became embedded in his head below the eye. The programme makers regard the DDS 3D facility as the most appropriate in the UK with which to study this celebrated example of early surgery where the surgeon/blacksmith was able to remove the arrow. Part of the programme was filmed at the DDS with a neurosurgeon describing the procedure using 3D visualisation. (See Figure 13)

Designing Out Infection

Funded by Birmingham NHS, in partnership with MidTech Innovations, this project focuses on building and developing a strategic design methodology that addresses infection control and reduction.

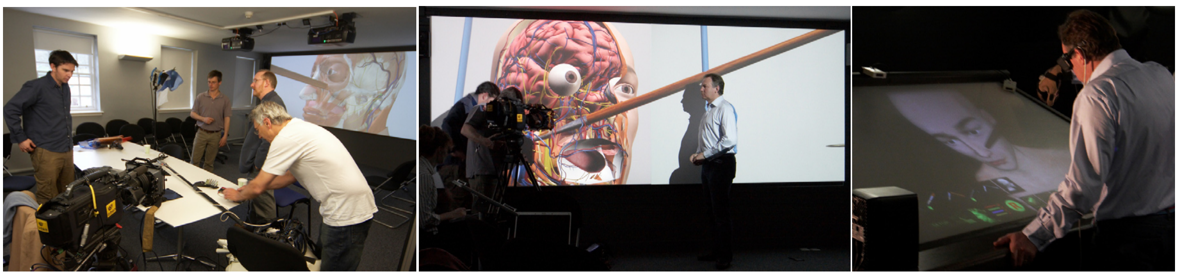
Phase 1 (£25,000), was a twelve-month study completed in December 2007. It focused on the identification of suitable areas for intervention. It produced preliminary proposals to support a strategy for 'Designing Out Infection', and in the process, informed and educated various parties as to how product opportunities are assessed and developed. Investigations were conducted through a literature review, interviews and hospital visits.

Phase 2 (£20,000) started in April 2008 and builds on the success of Phase 1 and focuses on building rapid prototypes of mobile stands and equipment as they are associated with the spread of contaminants and infection.

9.2 Ultrasound Anatomy and Techniques for Regional Anaesthesia

A collaboration between GE Healthcare, the Digital Design Studio and The Scottish Medical Visualisation Network has been proposed to develop a new interactive teaching package to demonstrate ultrasound anatomy and techniques for regional anaesthesia. This new, interactive training package will employ interactive 3D tools and models that are anatomically groundbreaking in their clarity

Figure 13: Documentary on Mediaeval Medicine - images from filming (from left): filming at the Digital Design Studio; using the wide screen display to illustrate the problem; explaining the procedure using the AutoEval 3D interaction system.



and interactivity. The proposal, valued at £180-200K has been accepted at both UK and EU level, and is awaiting approval from the GE Healthcare USA.

Arthritis Research Campaign (ARC)
The ARC has moved toward the commissioning of educational projects rather than inviting them through open call. Negotiations are beginning with ARC for commissioned research that fits with their new educational strategy (published in January 2008). Mike Patnick from ARC visited the DDS in February 2008 to hear about the activities of the Network and the potential for new research development. A further meeting with ARC's London office is being arranged.

PhD Studentship
The first Network PhD is expected to start during 2008. This studentship, funded by Ayr Hospital, will be part time, and based in the DDS where Professor Paul Anderson will be the lead supervisor with a second supervisor appointed from Glasgow University Medical School.

9.3 Contacts in Development
The Network is continuing to develop contacts with individuals and organisations through meetings and events.

Scottish Medical Illustrators Workshop
In June 2008 the Scottish members of the Institute of Medical Illustrators (IMI) held a workshop at the Digital Design Studio (DDS) for an introduction to the Network and its research activities. Professor Anderson reprised the activities of the Network and discussed the portential for future intercation with IMI in new research initiatives.

The IMI is the Illustrators' professional institute of choice and the leading body of its kind in Europe. Recognised by the Department of Health, the IMI exists to promote the role of the Medical Illustrator as a professional member of a multi-skilled team who offer a range of core clinical illustrative and communication services as part of the healthcare team for the benefit of patients and clients.

Contacts
The Network continues to develop strategic contacts for future development from a range of academic, medical and industrial organisations including the Scottish Government. These include :

- The Heads of the Scottish Clinical Skills Network based in Aberdeen, Stirling and Dundee.
- MEDiVision. This Australian company, which has links to RCS, manufactures medical simulators. They are interested in our techniques and a potential partnership.
- The Committee has made direct contact with the Chief Medical Officer for Scotland and presented the future strategy for the Medical Visualisation Network. As a result of this meeting, the CMO has recommended that the Deputy First Minister be appraised of the activities of the Network and its potential contribution to medical education and patient safety in Scotland.

10 New Strategies

The future vision for the Network is to develop funding streams that will support a dedicated full-time research and development team over the next four years based at the new DDS facility based at Pacific Quay in Glasgow. This facility is due to come on line in March 2009. Lab 1, in this facility will be one of the largest 3D interactive labs in Europe and will be focused on developing the first definitive dataset for the 3D interactive digital human. This ambitious research and development programme was recently presented to the CMO. The creation of this dataset, will allow innovative approaches to anatomical teaching and research for the five medical schools across Scotland. Key areas for development will include patient safety, promoting safe practice and reducing risk.

It is intended that the multi-disciplinary nature of the Network will expand to include paediatricians, physiotherapists, paramedics, nurses and dentists. The creation of the definitive anatomical data set for both male and female will allow significant research development to take place across a range of disciplines.

As a result of the activities conducted within the Feasibility Study, the Committee identified a set of future aims for the Network, together with four thematic areas of applicaton. These areas have been selected where 3D visualisation and interaction are likely to have the most immediate impact. These aims are:

10.1 Future Aims and Themes

- To create the first definitive data set for the 3D digital interactive human (male and female)
- To establish an interdisciplinary network for new approaches to medical teaching and clinical diagnosis.
- To create innovative techniques, tools and methodologies to support anatomical teaching and training.
- To develop 3D visualisation and interaction in support of surgical rehearsal and pre-operative planning.
- To promote understanding of lifestyle behaviours, disease processes and healthcare issues in a patient centred context and to the wider general public through visualisation.
- To enhance post-care management through visualisation to positively impact on patient recovery.

10.2 The Four Thematic Areas:

Promotion of Public Health for Scotland

Improving the health of the Scottish population remains one of the major challenges facing policy makers, educators and clinicians. Organisations in Scotland and the UK such as Health Scotland, the Royal Society for the Promotion of health and the Faculty of Public Health, already exist to promote continuous improvement in human health world-wide through education, communication and the encouragement of scientific research.

Public education and engagement with healthy lifestyle choices is key to improving the health of the nation over time. By using the latest interactive imaging, the Network can promote engagement with the health message, and enhance understanding. This will appeal particularly to the younger generation who are naturally comfortable with 3D interaction through computer games.

Visualisation techniques offer an opportunity to communicate clearly to the general public that preventative care and precautions can be taken to reduce, minimize, control or avoid a range of potential diseases resulting from addictions, poor diet, weight loss/gain or levels of fitness. They can play a supportive role in both reducing potential problems in later life and raise awareness of lifestyle behaviours and their impact on health.

The downstream implications of reducing the impact on the NHS could be potentially significant allowing Scotland to improve its rating in the European health tables.

Training and Anatomical Teaching

Digital imaging has been able to transform the way in which we obtain and interpret x-rays and scans of the body. However, interpretation of these scans is not easy and must be made in the context of expert anatomical knowledge. Disciplines such as radiology and surgery demand high-level skills based on undergraduate and postgraduate skill acquisition.

In recent years, the nature of undergraduate teaching has changed in response to increased time pressure between subjects and growing class sizes. The amount of face-to-face teaching in core subjects such as anatomy has been heavily reduced. As practical resources have become pressurised, increasingly, medical teaching has revolved around personal study and internet resources. This, combined with the reduced availability of human cadavers under a new EU directive on the use of chemicals in treating cadavers, has led to some concern about the future of traditional teaching methods.

A number of technological advances have been identified which can contribute to surgical training and reduce dependence on cadavers: restructured animal tissue models, synthetic tissue models, and virtual reality simulation. However, restructured animal tissue models require considerable technician resource, and thus preclude adoption on a large scale, whilst the simulation of complete operations on synthetic tissue models is limited in scope and very expensive.

Thus, VR is a realistic proposition for the training of both generic and surgical skills. Bertie Woods, Her Majesty's Inspector for Anatomy for Scotland and a member of the Network Board, believes the Government should be encouraged to fund the teaching of anatomy in 3D.

Recent developments in digital visualisation can revolutionise anatomical teaching with a return to the virtual 3D body. Current 2D computer based systems are limited in their usefulness and have had a minimal impact on teaching. A combined approach by visualisation experts, educationalists and clinicians within the Network, can address this problem.

3D interactive digital imaging would allow the basis of anatomical knowledge to be taught using real 3D perspectives with real-time or accelerated dynamic representation of physiology and disease in action. Students of all levels and disciplines would be able to interact with, explore and discuss anatomy as they once did in a wet lab, but in an accessible and timely fashion.

Gross anatomy coupled with informative animations demonstrating complex cellular biology and pathophysiological processes would provide an unrivalled research and teaching tool capturing the imagination of doctor and lay person alike. Such a resource, once developed, could be rolled out on a large scale, and could potentially simulate a range of pathologies.

The case studies completed by the Network have demonstrated the benefits of such techniques in understanding complex anatomy such as the Inguinal Canal and Lung Collapse, and in developing skills such as conducting a Lumbar Puncture. These benefits are already being harnessed in the development of new projects such as the Visualisation of the Anal-Rectal Junction and the Chest Drain Simulator, both funded by NES.

Surgical rehearsal and pre-operative planning

Digital prototyping and interaction with volumetric data in 3D with haptic devices is a very real possibility. Interactive digital applications can build on what has already been achieved in virtual colonoscopy and computer-aided pulmonary nodule detection to expand what is potentially the most exiting teaching tool and clinical aid within our immediate grasp.

Interest is also being shown in the use of visualisation techniques as decision-making tools for surgeons, particularly with regard to studies in psychological loading.

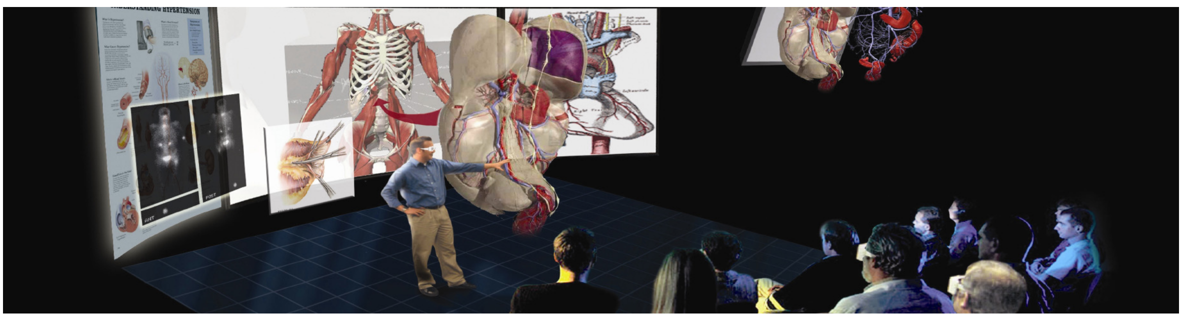
Post-care management

Modern medicine relies on a broad range of skilled professionals who must work together to ensure the best outcomes for the individual patient. Enhanced visualisation allows for interactive discussions between team members, the team and the patient.

Patients need to understand the procedures and treatments they are offered. Through 2D and 3D interactive imaging, information can be communicated clearly to the patient.

This could range from explanation of disease processes, a degenerative condition or everyday surgical procedures, post care management and recovery regimes. Considered application of such techniques could empower patients' decision making, and reduce their anxiety. A patient's understanding of the route to health has been found to have a positive profound impact on patient recovery terms.

Figure 15: Concept image showing 3D visuallisation in medical teaching.



10.3 Enhanced Case Studies

Considerable interest has also been shown in the further development of the five case studies described above, and on extending such techniques to other areas. Such development is likely to require full-time expertise and industrial collaboration.

11 Recommendations and Future Plans

The Scottish Medical Visualisation Network Feasibility Study has successfully established a partnership between a large number of medical professionals, researchers and students across Scotland and reached out to partners in the rest of the UK and internationally.

To ensure this momentum is maintained, the following recommendations are made.

- The network should be expanded to encompass all medical disciplines in Scotland.
- Nurture medical student involvement in the formation of a dedicated interest group within the Network.
- Build upon the large body of expertise across the disciplines within the Network to attract significant projects with international visibility, putting Scotland to the forefront of medical visualisation research.
- Develop the case study models. In particular, an approach needs to be identified to develop the inguinal canal and lung collapse studies to the next level.
- Strengthen the link to key industrial players to commercialise the intellectual property developed within the Network.
- Establish the DDS as a Hub to undertake research development activities and disseminate visualisation technology. This Hub will share data and disseminate research outputs to five other centres across Scotland.

Figure 16: Still from a 3D animation of proposed Lab1 at Pacific Quay – new premises for the Digital Design Studio from 2009.

The Network has already succeeded in bringing together key persons and organisations across Scotland. With infrastructure and research funding in place, the Network can have the capability to establish Scotland as a world leading centre in medical visualisation both academically and commercially, by providing the tools that practitioners need.

12 Financial Plan for Future Development

A four-year financial plan has been created that will provide the necessary research and development capability to the Network whilst it works towards becoming financially self sustaining.

It is essential that the Network develops a core research team appropriately equiped. This will allow Professor Paul Anderson to lead two research programmers and two 3D modellers to develop the definitive 3D Digital Interactive Human. This will provide an anatomically accurate dataset from which teaching materials, training simulations and commercial products can be developed. This ambition is at the heart of the Network's current activities and future aims as outlined in Sections 9 and 10.

The research programmers are expected to be of post-doctoral standing and with a research track record in either medicine or visualisation.

The highly skilled 3D modellers will have expertise in the latest modelling techniques and will be trained to use highly specialised 3D digital laser scanning equipment. They will work closely with a range of medical disciplines across Scotland.

A full-time administrator is required to coordinate the Network including membership

Item	Description	Cost
Directly Incurred Costs		
Researchers/Programmers	Direct cost of 2 researchers based at the DDS for four years including superannuation and NI.	£380,346
Modellers	Direct cost of 2 dedicated modellers for four years including superannuation and NI.	£311,323
Administrator	Direct cost of a full-time administrator for four years	£108,282
Travel	Budget dissemination of research including major European and International conferences.	£25,235
Other	Equipment, tools, technologies and software for case studies, 2 workshops per year and a marketing budget.	£322,538
Directly Allocated Costs		
Management Costs	Services of Professor Paul Anderson (0.5FTE) to direct the project for four years.	£186,982
Indirect costs		
Estates	Rates set by Institution; calculated on FTE	£171,167
Indirect	Rates set by Institution; calculated on FTE	£675,407
Total Expenditure		£2,181,280

issues, web content management, marketing, organising meetings of the advisory committee whilst organising and coordinating two workshops per year.

A travel budget of £25,235 is included as it is anticipated that the research carried out by this team will result in high quality research outputs which will be disseminated at the highest level. This will involve the team travelling to conferences all over the world approximately 10 in UK/Europe and 10 outside of Europe are anticipated over a four year period.

Specific equipment required includes a highly specialised portable 3D digital laser scanner. This is required to provide real-time measurement data and is capable of scanning parts of the body to sub millimetre accuracy. It will allow the team to produce a high quality anatomically accurate dataset with photo accurate texture maps not currently available anywhere. The scanner is expected to cost £117,500K.

High end computers with the latest software and a base 3D female model will also be required. Software will need to be updated yearly; it is estimated that initial costs and upgrades will be around £105,163K.

£29,375K has been included as a marketing budget, £11,750 for web site hosting and development, and £70,500K for the cost of hosting eight workshops over four years at national level for around forty delegates. The workshops will be used as a means to disseminate the research to the Network and get their feedback and input to further research.

The success of the Scottish Medical Visualisation Network will require a committment from Professor Paul Anderson equvalent to 2.5 days per week.

It is hoped that this dedicated research team will be located at the new DDS facility at Pacific Quay in Glasgow. Negotiations are also ongoing for at least three sponsored Fellowships across medical disciplines. The Network's first sponsored PhD student will start at the Digital Design Studio in October 2008.

End of Report