Using multimedia and Web3D to enhance anatomy teaching

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Abstract

Anatomy teaching is undergoing significant changes due to time constraints, limited availability of cadavers and technological developments in the areas of three-dimensional modelling and computer-assisted learning. This paper gives an overview of methods used to teach anatomy to undergraduate medical students and discusses the educational advantages and disadvantages of using three-dimensional computer models. A ‘work in progress’ account is then given of a project to develop two Web3D resources to enhance undergraduate tuition of the nervous system. Our approach is to support existing curricula using advanced modelling tools and a variety of delivery mechanisms.

The first resource is a three-dimensional model of the adult brachial plexus: a network of nerves extending from the neck down to the shoulder, arm, hand, and fingers. This will be incorporated into existing didactic classroom teaching under the supervision of an anatomy teacher. The second resource is a piece of online courseware which will teach the embryological development of the brachial plexus. The delivery method will be the WebSET framework, a collaborative environment that allows a teacher to manipulate 3D models over the Web in real time whilst providing explanation and help to students. In this way the courseware can be used for both self-directed study and ‘virtual anatomy demonstrations’ within an online peer group.

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1. Introduction

Human anatomy is the scientific study of the form, position, size and relationship of the structures in the body. It can be divided into gross anatomy (the structure and positioning of organs), histology (the microscopic study of cells and tissues), embryology (the formation and early development of the foetus) and neuroanatomy (the study of the brain, spinal cord and peripheral nervous system).

This paper starts with an overview of common methods of teaching anatomy. It then describes the technical process of creating computer-generated three-dimensional models of human anatomy and discusses the advantages and disadvantages of their use within education. An account is then given of an ongoing project at Imperial College London to create two Web3D resources to enhance tuition of the nervous system to undergraduate medical students. This project is at an early stage of development and is a ‘work in progress’ yet to be completed and evaluated. It is included in this paper to help illustrate the methodology behind building a Web-based three-dimensional application for teaching anatomy.

There is considerable debate within the medical community about the best ways to teach anatomy. Interest in Computer Aided Learning is growing (Mitchell & Stephens, 2004) but this needs to be supported by further research to evaluate the impact of multimedia resources upon student learning.

2. Methods of teaching anatomy

2.1. Dissection and prosection

Since the Renaissance the dissection of cadavers has underpinned anatomy tuition (Porter, 1999). Many believe that cadaveric dissection provides undergraduates with an essential foundation in medical science. Benefits include:

1. Learning the basic language of medicine needed to describe the structure (anatomy) and function (physiology) of the human body
2. Establishing the primacy of the patient as a person as opposed to a series of diagrams or photos in a textbook
3. Acclimatising students to the realities of death
4. Teaching manual dexterity and touch-mediated perception
5. Introducing the concept of anatomical variation (there are significant internal differences between humans)
6. Gaining knowledge of the three-dimensional spatial relationship between structures
7. Gaining communication skills within a small peer group (adapted from Aziz et al., 2002; Ellis, 2001).

Dissection is traditionally taught topographically by studying the anatomical structures in a particular region of the body. A systems-based approach is now more common, the reproductive system or respiratory system, for example, being examined as discrete units. Prosections are
pre-dissected specimens; James et al. (2004) review six studies that compare the examination results of students learning from prosections and dissections. The evidence is not conclusive but does indicate that undergraduates perform as well if not significantly better in examinations when they learn from prosections.

2.2. Lectures and problem-based learning

The lecture theatre allows basic anatomical facts and concepts to be transferred from one teacher to many students who can then supplement what they have learned with private study. This stalwart bastion of educational practice remains a useful way of disseminating knowledge efficiently and cost effectively. However lectures and books poorly convey the three-dimensional nature of anatomical structures and do not encourage collaboration or develop problem solving skills.

Problem-based learning (PBL) aims to address the weaknesses inherent in didactic instruction by encouraging independent thought and teamwork. In a typical PBL session a small group of students is presented with a real-world medical problem such as a serious head injury. The tutor or ‘facilitator’ tells students which parts of the case are related to anatomy and gives them a list of appropriate resources such as textbooks, journals, videotapes and websites. Each student researches the scenario individually before returning to the group to collectively discuss and assess what they have learned.

2.3. Radiological imaging

Lectures, PBL sessions and dissection classes often incorporate radiological images. These are typically magnetic resonance (MR) or computerised tomography (CT) scans that show two-dimensional cross-sections through the body (Fig. 1). Interpreting these images takes considerable expertise because students have to mentally reconstruct a two-dimensional slice into a three-dimensional visualisation which may have been altered by disease or accident. The ability to correlate diagnostic scans with living patients is a skill that many junior doctors will find essential in their future clinical practice.

2.4. The Visible Human Project and anatomy websites

In 1994 The Visible Human Project (Ackerman, 2004) provided colour scans of a middle-aged human male sliced into 1871 cross-sections at 1 mm intervals (Fig. 2). The Internet Atlas of Human Gross Anatomy (Jastrow & Vollrath, 2002) is based on the visible human dataset and provides a wealth of annotated material. Many similar websites incorporating the Visible Human Project do not charge a registration fee and can be used by students for self-directed study or incorporated into classroom teaching. There is also a female visible human, as well as Chinese (Zhang et al., 2003) and Korean (Zhong, 2003) equivalents, that make use of recent technological developments to produce very high fidelity images.

A survey of German undergraduates indicated a high demand for online anatomy resources with students reporting that they are more motivating and ‘fun’ than textbooks (Jastrow & Hollinderbaumer, 2004). The most valued material was relevant to examinations, included high quality images, allowed keyword searches and contained up to date information. In another
study, students who used Web-based material to learn anatomical landmarks performed better in midterm and final examinations than a control group who did not have access to the material (Hallgren, Parkhurst, Monson, & Crewe, 2002). Self-assessment exercises and real time feedback are an important component because they help students assess their own knowledge and highlight areas that require further study.
2.5. Combining a range of approaches

There is no prescribed template for anatomy tuition and most modern courses use a range of methods including imaging, classroom teaching, PBL and dissection of cadavers (Mitchell & Stephens, 2004). Classes in a dissection room are sometimes supported by demonstrations of ‘living anatomy’ where students examine each other’s bodies in relation to the cadaver on the dissection table (Ellis, 2001). Likewise, a PBL session may incorporate the study of prosections in the dissecting room. The use of plastic models is common although these have been criticised for not showing natural human variation and giving a falsely sanitised and homogenous view of anatomy.

Plastinated models differ significantly from plastic models because they are real anatomical specimens which have been preserved with reactive polymers. These have gained notoriety due to Gunther Von Hagens Bodyworlds exhibition (Hagens, 2004). Other innovative approaches include laparoscopic imaging of live patients to demonstrate upper abdominal anatomy (Park et al., 2001) and plasticine models to teach embryology (Nunn, 2004).

2.6. Curricular changes

In the last 20 years there has been a severe reduction in the time devoted to anatomy teaching and a drop in staffing levels (Heylings, 2002). This trend is international (Aziz et al., 2002; Parker, 2002) and has contributed to a considerable debate within the medical community about the best methods of teaching anatomy in an efficient and cost effective manner (James et al., 2004).

2.7. Removing cadaveric dissection from the undergraduate curriculum?

The necessity for undergraduate dissection of human cadavers has been challenged. For example, The Peninsula Medical School in the UK has replaced cadaveric dissection with an approach that relies upon multimedia, problem-based learning and computer imaging (McLachlan, Bligh, Bradley, & Searle, 2004). They concentrate on anatomy that will be directly relevant to the management of clinical problems presented by patients and they believe that dissection is more suitable for postgraduate specialities such as surgery. This approach has been challenged by those who believe multimedia, PBL and radiology should supplement rather than supplant dissection (Ellis, 2001; Mitchell & Stephens, 2004).

Both schools of thought agree that there needs to be more research done to evaluate which teaching methods and techniques are best to train the next generation of doctors.

3. Three-dimensional computer generated anatomy models

This paper will now examine the use of anatomical three-dimensional modelling. To help illustrate the methodology behind building a Web-based three-dimensional application we give a ‘work in progress’ account of the development of two Web3D anatomy resources.
3.1. Modelling techniques

Websites and CD-ROMs produced by companies such as Primal Pictures (www.primalpictures.com; Ward, 2002) provide three-dimensional reconstructions of the human body with controls to peel back tissue and bone revealing previously hidden layers (Fig. 3). Creating these three-dimensional models involves a number of technical stages: scanning, enhancement, segmentation, and volume or surface rendering (Figs. 1 and 4).

3.1.1. Scanning

A coordinated series of 2D images is acquired using a scanning technique such as CT or MRI (Fig. 1) or by digitising cryosections (Fig. 2). Each image shows a slice through the body at regular intervals, typically of 1 mm. The type of imaging modality used can be varied to suit the requirements of the disease/clinical indication. For example, CT is often used to image colorectal cancer.
because it presents a detailed picture of how far the cancer has spread to areas surrounding the colon. MRIs are often used to plan neurosurgery because they are good at imaging vital structures in soft tissues which must be avoided when removing adjacent tumours.

3.1.2. Enhancement
The raw images are digitally manipulated to enhance image quality. Common techniques include contrast enhancement, noise reduction and interpolation. Enhancement must be done with great care as it can emphasise image artifacts and even lead to a loss of information if not correctly used.

3.1.3. Segmentation
Vector drawing tools are used to trace a chosen region in a scan, such as the liver (Fig. 5). This process also has the effect of electronically tagging an area so that it can be uniquely addressed and manipulated. Without segmentation unwanted regions may get included when the series of
2D images is reconstructed in 3D. Segmentation can be done manually but it is a slow and laborious task. Automated or semi-automated segmentation software (Bartz et al., 2004) can help speed up the process by using various techniques such as pattern recognition to help extract the border of structures.

3.1.4. Volume or surface rendering

Once segmentation is complete, the software processes each 2D slice in turn to build a 3D volume dataset. Volume data is suitable for medical images because it shows the inside of solid objects and allows outer layers to be cut away. However, real-time interaction is limited because each new view must be fully recomputed, requiring substantial processing power.

A common way of extracting polygonal surface information is to use the ‘marching cubes’ algorithm (Lorensen & Cline, 2004) which tests each voxel in turn in order to locate the boundary of a wanted object within a 3D array of voxel values. The data are then used to construct a numerical description of the surface. Because the surface is computed only once, the viewpoint can be rapidly updated allowing for fast interaction. However, it is not possible to cut away outer layers to show the inside of solid objects. Once a surface dataset is created it can be conventionally texture-mapped using software such as the Visualisation Toolkit (Schroeder, Martin, & Lorensen, 2004).

3.2. Advantages of three-dimensional modelling

The most obvious benefit of 3D models is the ability to view the spatial relationships between structures from numerous viewpoints. This addresses a crucial educational need: ‘it takes time and practice to develop the ability to visualise in three dimensions...insufficient ability to visualise is frequently expressed by students who have difficulty identifying structures in the living body as required in clinical examination’ (Heylings, 2002). This is in marked contrast to textbook diagrams, photographs, MRIs and CT scans which do not show spatial relationships, require expertise to interpret and may lack sufficient detail to properly illustrate a particular teaching point. Diagrams can use shading to give the illusion of 3D (Fig. 6) but the viewpoint is fixed and cannot
be manipulated to reveal hidden details. Presenting radiological images alongside equivalent 3D models helps students to learn the crucial skill of mentally transposing a two-dimensional image onto a three-dimensional patient.

Diagrams and radiological scans show a static snapshot in time whereas 3D models can be presented within a narrative timeline which a viewer can rewind, pause and fast forward at their convenience. This can be used to demonstrate anatomical development, physiology or the progress of disease (pathology) upon an organ. Having a clear timeframe is especially important in understanding pathology because the rate at which a disease spreads through the body is often not constant.

Three dimensional models are often presented as an equivalent to the ‘museum display’ of specimens found in many dissecting rooms. Students can study an electronic museum display whenever they choose and digital specimens do not have to be replaced every three years as mandated (in the UK) by the Anatomy Act (Heylings, 2002). Digital models are of a universal standard whereas prossections can be of variable quality and have limited interaction. Three-dimensional resources are a ‘lingua franca’ that can be supplemented by language-specific annotations, didactic material and self-test quizzes. Specialised CD-ROMs have addressed niche areas such as sports injuries (Betts, Saifuddin, Marone, Wolman, & Lambert, 2004).

### 3.3. Disadvantages of three-dimensional modelling

The construction of anatomically correct three-dimensional models demands much time and great patience. It is hard to compare the financial implications of traditional and multimedia instruction because no studies have been published that analyse the time/cost benefits of anatomy teaching supported by 3D technologies. Web3D is unlikely to be widely adopted by educators unless they can see clear evidence that demonstrates its effectiveness and financial viability for their teaching. There are few common standards for validating Web3D resources, evaluation is often informal and rarely examines the longitudinal retention of knowledge by students. Pilot studies can paint an unrealistic
picture of the constraints that many university departments operate under: no matter how technically innovative an approach is, budget holders will purchase tools that have a demonstrated ability to raise learners to a prescribed level of proficiency within a set time period.

Three-dimensional models will always be iconic abstractions of the real body. Gauging the required level of detail and stylisation for educational instruction is not an exact science, and too little or too much information can be detrimental. Trial and error, qualitative feedback and personal judgement are common strategies. The publication of more case studies of ‘real world’ development, including mistakes, pitfalls and practical advice, would be beneficial to the academic community.

Authoring tools to create Web3D models have been slow to develop and complex to learn, increasing development time and cost. Many file formats for 3D models are proprietary and cannot be easily exchanged although the situation is improving with ISO approved standards such as X3D (X3D, 2004) and H-Anim H-Anim (2004) which encourage sharing, reuse of models and greater integration with existing Learning Management Systems and Virtual Learning Environments (Chittaro & Ranon, 2007).

Other disadvantages:

- Students require a PC with a moderately powerful 3D graphics card;
- Web3D requires browser plug-ins which may fail to run under recent security restrictions added to Microsoft Windows XP;
- 3D navigation controls need to be intuitive, otherwise the interface can interfere with the content;
- Interacting with 3D models with a mouse does not convey a sense of touch or weight.

4. Two Web3D resources to enhance tuition of nervous system

At Imperial College London, we are experimenting with new ways of teaching anatomy using emerging Web3D technologies and collaborative online environments. The project team consists of a Professor of anatomy, an anatomy Lecturer, a surgeon, a Lecturer in medical graphics and a learning technologist. We are currently working on a project to create two Web3D resources to help teach the structure and function of a network of nerves called the brachial plexus. The first resource is a three-dimensional model of the adult brachial plexus which will be incorporated into existing classroom teaching. The second resource is a piece of courseware which will teach the embryological development of the brachial plexus. By creating two different resources we aim to evaluate the educational benefits of Web3D for both self-directed study and didactic instruction.

Even though this project is in the early stages of development it provides a useful example of the methodology used in creating medical Web3D resources.

4.1. The brachial plexus

The brachial plexus is a network of nerves originating from the spinal cord, emerging between the vertebrae in the neck and extending down to the shoulder, arm, hand, and fingers (Fig. 7). Brachial refers to the arm, plexus means network. Our aim is to use computer-aided learning
to help students gain a deeper understanding of the embryological formation of the brachial plexus and how the nerves in a fully formed plexus supply sensation to the whole limb. A good understanding of these concepts provides an educational scaffold from which to develop the diagnostic skills necessary to infer the consequences of trauma or disease.

The nervous system is an important part of the undergraduate medical curriculum and one that students often have difficulty conceptualising in three dimensions. This makes it a particularly suitable topic for an educational Web3D application.

4.2. Student learning objectives

Students are expected to: memorise the structure of the brachial plexus; understand how the brachial plexus relates to the peripheral nervous system and the anatomy of the upper limb; develop an ability to clinically evaluate how nerve injuries affect the upper limb.

4.3. Student learning strategies

The structure of the brachial plexus is very hard to remember; one student referred to it as ‘like trying to memorise Clapham Junction’ (the busiest railway station in the UK). At Imperial College London the brachial plexus is taught in a 1-h lecture and in practical sessions studying prosections for between 60 and 90 min. This is supplemented by private study in the library with anatomy textbooks.

Printed diagrams and photographs are useful but they encourage superficial rote learning and a surface understanding of the subject. Two-dimensional representations are of limited educational value because the nerve roots and fibres grow to form a complex arrangement within a three-dimensional space. Prosections go some way to acquiring this spatial visualisation but there is limited time in the dissection room for extended study and they are not always available for revision. Cadaveric specimens are surprisingly different to what a surgeon sees and feels when operating on
a living patient. In living tissue the nerves are bound closely together around arteries and bone, whereas structures in prosections have often been teased apart to help demonstrate the structure of nerve roots and branches. In addition the process of fixation and storage significantly changes the colour, texture and consistency of human tissue.

4.4. Development tools

We are using Alias/Wavefront Maya (Maya, 2004) as the central development environment. Maya is a powerful commercial software package used on numerous films and television commercials. It has advanced tools for modelling and animation including skeletal simulation, dynamics simulation, particle effects, cloth, hair, fur and liquid simulation. A recent discount has brought the cost within reach of most educational budgets (reduced from £5000 to £400).

4.5. Level of detail

The level of detail for the brachial plexus project is tailored to suit a medical student learning the developing interconnections between nerves, muscle and bone for the first time.

4.6. Web3D resource 1: the adult brachial plexus model

The adult brachial plexus will consist of an interactive three-dimensional model which can be manipulated to show the structure from multiple angles and viewpoints. For example, one view will show the nerves compacted together as they appear in the visible human dataset (Fig. 7), another will present the nerves in the form of a diagramatic representation (Fig. 8).

4.6.1. Modelling the spine

A model of the lumbar vertebrae and pelvis has already been built (Fig. 9) to simulate a lumbar puncture (John et al., 2001). The model was constructed from the visible human dataset using standard segmentation and reconstruction techniques and then converted into Virtual Reality Modelling Language (VRML), a common language for describing and displaying 3D content (Dodd, Riding, & John, 2004).

Since this model comprises only the lumbar vertebrae, we are currently extending the spine to include the upper vertebrae and spinal cord at the point where the brachial plexus originates. Segmentation and reconstruction is time and labour intensive, therefore we are assessing the feasibility of creating vertebrae directly within Maya. To do this we took screenshots of polygonal vertebrae built using an online version (Bessaud & Hersch, 2004) of the visible human dataset (Figs. 7 and 10). These were then used as a tracing image to provide guidelines for the creation of a subdivision surface model (Warren, 2002). Sub-division surfaces use curves (splines) rather than polygons (triangles) to describe a geometrical object. Preliminary results of this technique (Fig. 10) are encouraging, suggesting that vertebrae of sufficient fidelity to suit our purposes can be created using this procedure.

A comparison between the polygonal and spline-based models in Figs. 9–11 shows the significant increase in quality gained from using sub-division surfaces. Maya supports many other rendering formats and techniques, which we will experiment with to further increase realism.
Fig. 8. Diagrammatic view of the adult brachial plexus (being modelled in the Maya development environment).

Fig. 9. VRML model of the lumbar vertebrae.
4.6.2 Modelling the nerves

The nerves have been modelled in Maya with reference to textbook diagrams and the visible human dataset (Figs. 7 and 8). Once modelling of the upper vertebrae is complete, the nerves will be added.

4.6.3 Future work: classroom delivery using a web browser, X3D and H-ANIM

We aim to use X3D (X3D, 2004) and H-ANIM (H-Anim, 2004) to deliver high quality spline-based models that can be interacted with over the Internet in real time. X3D is an XML-based...
successor to the VRML 97 standard, H-ANIM is a standard for representing three-dimensional humanoids. We plan to evaluate the model within existing didactic teaching, with an anatomy demonstrator using it as a teaching aid in the classroom.

The specifications for the finished resource are still in the planning stages. The tool will include an interactive X3D model of the adult brachial plexus with annotated pop-up labels explaining structure and function. This will be supplemented by teaching material such as high quality pre-rendered subdivision quicktime animations, two-dimensional flash diagrams, photographs of prosections, and links to relevant websites and academic papers.

4.7. Web3D resource 2: the embryological development of the brachial plexus

The embryological development of the brachial plexus is the subject of a lecture given by a Professor of anatomy at Imperial College, London. The lecture represents an original approach to the subject and it forms the ‘storyboard’ for the creation of the electronic learning resource. Embryology can give a profound insight into adult functioning, but with increasingly less time devoted to anatomy teaching it has almost disappeared from some courses (Heylings, 2002).

4.7.1. Work in progress: segmentation and modelling

The nascent nervous system is too delicate to image using traditional segmentation techniques. Consequently we are using the vector tools in Macromedia Fireworks to trace the outline of a growing limb from a series of human embryo MRIs showing 10 key ‘Carnegie’ stages of embryonic growth between 28 and 54 days (Fig. 12).

Fig. 12. MRIs showing segmented cross-sections of a human embryo limb bud.
The segmented vector outlines created in *Macromedia Fireworks* are imported into *Maya*. These act as guidelines for modelling the embryonic limb bud (Fig. 13). Because the developing nerves are too fine to image using conventional MRI, the nerves are added manually as subdivision surface cylinders. To ensure accuracy, reference is made to scans of the brachial plexus of a dissected rat embryo enhanced by dye injection and nerve staining (Aizawa, Isogai, Izumiya, & Horiguchi, 1999).

4.8. Future work: delivery using WebSET

WebSET is a European Union funded project to develop Web-based educational courseware (John et al., 2001). It comprises a set of tools that allows 3D simulations to be integrated into Web-based training packages using a common Java plug-in (the Cortona VRML Client). WebSET has been used to simulate surgical procedures (Fig. 14) such as a lumbar puncture (using a needle to draw fluid from around the spinal cord), allowing a student to practise the technique within a collaborative environment monitored by a teacher. Lecture notes, videos, MCQs and feedback on

![Image of a 3D model of a limb bud with vector outlines created in Macromedia Fireworks](image.png)

Fig. 13. Modelling the embryonic human limb bud using vector outlines created in *Macromedia Fireworks*. 
performance metrics supplement the 3D simulation. WebSET has been evaluated and shown to place students higher up the learning curve towards surgical competence (Moorthy et al., 2003).

4.8.1. Collaborative environment

Undergraduate medical students require information about the structure of the body but this propositional knowledge needs to be learned within an appropriate educational context. Models in themselves are of little educational or professional value without a carefully considered framework for delivery.

Medical virtual environments (Vidal et al., 2004) offer opportunities for collaborative learning which may be usefully applied to Web3D anatomy resources. Chittaro and Ranon (2007) argue that virtual collaborative environments provide valuable first-person substitutes for real experience and encourage ‘spontaneous knowledge acquisition that requires less cognitive effort than traditional educational practices’. They draw upon constructivist theories to demonstrate how Web3D technologies can enhance online collaboration, giving as an example the way a group Brazilian school children work together, actively construct and learn about their own virtual world.
Engagement in this type of complex, personally meaningful task, is in marked distinction to the weak opportunities for interactivity and collaboration in the current generation of Virtual Learning Environments (VLEs), which reinforce behaviourist models of learning (Bonk, Wisher, & Lee, 2004). Text-based discussion boards, email and chatrooms may have spawned a new linguistic medium (Crystal, 2001) but they lack the richness of perceptual cues and opportunities for teamwork found within modern 3D environments.

5. Discussion and evaluation strategy

Although the brachial plexus project is still in the early stages of development, the work we have completed thus far suggests that we can gain a significant improvement in the quality of three-dimensional models using Maya. We are planning to use a combination of X3D and HAnim for the delivery of the adult brachial plexus model, allowing sophisticated animation and manipulation of high quality spline-based models. We are currently evaluating a commercial X3D/H-anim authoring tool called VizX3D (VizX3D, 2004) to test its functionality and ability to integrate with Maya.

We intend to conduct a thorough evaluation of the finished system in the next teaching cycle. Our working hypothesis is that introducing the 3D model into existing teaching will improve students’ knowledge and retention of the brachial plexus in accordance with these learning objectives:

- An ability to memorise the three-dimensional structure of the brachial plexus;
- An understanding of how the brachial plexus relates to the peripheral nervous system and the anatomy of the upper limb;
- An ability to clinically evaluate how nerve injuries affect the upper limb;
- A good understanding of the formation of the brachial plexus and how the nerves innervate the whole limb.

5.1. Adult resource

Three groups of undergraduate students will be pre-assessed with multiple choice and short answer questions to test their existing anatomical knowledge of the brachial plexus. Group one will then receive traditional didactic teaching. Group two will then receive traditional didactic teaching supplemented by the 3D model. Group three will have access only to the Web3D tool and the supplemental teaching material on the website. Each group will then be post-assessed to determine any effect that the 3D tool had upon their learning. A questionnaire will also be completed by each student to obtain qualitative feedback.

5.2. Embryological model

The embryological model will be used to test retention of knowledge and the suitability of the tool for revision. Three groups of undergraduate students will be pre-assessed with multiple choice and short answer questions to test their existing anatomical knowledge of the brachial plexus.
• Group one will then use the tool for self-directed study;
• Group two will use the tool within a collaborative environment with one hour ‘virtual supervision’ by an anatomy teacher;
• Group three will act as a control. They will not have access to the tool and will revise the topic with traditional revision techniques;
• The three groups will then be post-assessed to determine any effect that the tool had upon their learning.

6. Future work

6.1. Haptics

Jastrow and Vollrath (2002) state that cadaveric dissection is the ‘only means of experiencing the consistency of organs and tissues’. This is challengeable on two counts, firstly because the storage and fixation of cadavers alters the color and texture of tissues being dissected. Secondly because ‘haptic’ (Hale & Stanney, 2004) technologies allow the simulation of touch and have the potential to accurately recreate the elasticity and consistency of living tissue. Haptics requires force-feedback devices, such as the Phantom (Phantom, 2004), which has recently reduced in price. Temkin, Acosta, Hatfield, Onal, and Tong (2002) have created three-dimensional anatomy models which can be palpated over the Internet.

6.2. ‘Intelligent’ models

Most anatomical 3D models are ‘dumb’ in the sense that the functioning of organs and limbs has been manually animated by a human. There are some exceptions, such as Garner and Pandy (2001), who created a computer simulation of the major articulations and contractions of bones, muscles and tendons in the upper limb and shoulder. The film industry has been a prime force in the development of musculoskeletal simulations. Special effects companies such as Weta Digital (Weta, 2004) are primarily concerned with the realistic deformation of skin, on characters such as cave trolls, but the tools they have developed are of potential benefit to anatomical modelling. Absolute Character Tools (CG Character, 2004) is one of the first commercially available tools for muscle simulation on a standard PC. Three-dimensional environments allow the physical embodiment of forces that are invisible in the real world. Abstract concepts, such as chemical bonds or money, can be given a perceptible representation with which users can interact. It is feasible that future anatomy models will include ‘intelligent tutoring systems’ (Brusilovsky, 1999) that will simulate and teach complex abstract physiological and biochemical processes.

6.3. Open source models

The visible human project is an excellent resource for two-dimensional images, but the process of segmentation and reconstruction into 3D models is time-consuming and costly. The medical community would benefit from an open source library of pre-built anatomic structures which could be used for non-commercial educational purposes.
6.4. MedX3D standard

The Web3D Medical Working Group is developing an interoperable standard called MedX3D for representing human anatomy (www.web3d.org/applications/medical/index.html). We will monitor this emerging standard and consider the benefits of including it in the final version of the courseware.

6.5. Online computer games

Three-dimensional Massively Multiplayer Online games such as Star Wars Galaxies (Starwars, 2004) highlight the paucity of interaction and collaboration within text-based VLEs. Every day thousands of players simultaneously engage in complex tasks and problem-solving activities within fluctuating groups linked by complex bonds of fealty, allegiance and shared localised codes of conduct. Players are encouraged to become guides, initiating newcomers into the etiquette of a complex virtual community of practice by providing mentorship, help and remediation. These types of computer games provide a 'proof of concept' for the next generation of educational collaborative 3D environments.

6.6. Postgraduate study

We plan to extend the brachial plexus model to include animated effects of disease and injury upon the plexus (brachial plexopathy). This will provide information useful to surgical and radiology postgraduates.

7. Conclusion

Anatomy teaching is undergoing significant changes due to time constraints, limited availability of cadaveric specimens and advances in computer-assisted learning. Web3D offers many potential benefits, most notably the ability to simulate the spatial relationships between anatomical structures. However, more research needs to be done to evaluate these resources before they are introduced into the undergraduate medical curriculum.

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