Eur J Anat, 7 (3): 147-159 (2003)

Application of the "*Visible Human Project*" in the field of anatomy: a review

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Summary

The present review addresses the most relevant applications developed using the Visible Human Project. We describe the origins of the Project and the procedure used for the collection of anatomical images of the cadavers from a man and a woman. Thousands of sections from these cadavers have been used in different ways, ranging from the generation of anatomical atlases to the construction of three-dimensional images for simulations and virtual training in surgery.

We also include a broad review of the literature and some Internet addresses where information concerning the different uses made of the project compiled by the National Library of Medicine can be sought.

Currently, the Visible Human Project is the best and most used digital reference concerning human anatomy, its application being broadest within the field of education. Nevertheless, its applications and uses have surpassed all expectations and the images are now being used in a huge area of disciplines such as art, industry, surgery, etc.

Key words: Visible Human Project – Anatomical atlas – Virtual dissection – Medical education

Introduction

The role of Informatic Technology (IT) in medical education began in the eighties of the last century under the influence of the use of PCs in medical practice (Jastrow and Vollrath, 2002, 2003). It expanded to a considerable extent in the following decade through integration of IT at international level (Internet, Telemedicine,…).

The development of new information technology in education is unquestionable, as is its use in medicine for the communication of medical knowledge (Gutiérrez, 1997). IT offers huge benefits both as regards teaching activities and professional training: decentralisation and access to the main data sources; recopilation and updating of knowledge; multidisciplinary assessment for problem solving and appropriate decision making processes.

The storage and processing of information is increasingly more important in the sphere of medicine. It is therefore crucial that all health professionals should acquire experience in the field of IT. The aim of International Informatic Medical Association is to foster this and it provides information to all professionals related to the field of health (physicians, nurses, administrative staff and specialists in medical IT).

As is well known, the Internet is a global network of computers spread across the planet. Thanks to the very impressive technological advances offered by current telecommunication and IT systems, it is widely used by people working in science. The storage and transmission of information through the Internet undoubtedly represents a new scientific, technological, social and economic revolution and it is a magnificent resource for the search for information in the field of the experimental sciences. It is therefore hugely attractive for teachers looking for class material, scientists wishing to access the latest

Submitted: July 21, 2003
Accepted: October 17, 2003

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developments in their discipline, and students in general. The three points on which the Internet revolution rests are its interactive nature, its global connectivity, and its independence of geographic location. The Internet can therefore be envisaged as a magnificent multimedia library since it contains information not only in text form but also in the form of images, sound material, and animations (Klein, 1991; Gutiérrez, 1997; Paternostro and Zecchi Orlandini, 2001).

As well as multimedia programs applied in the field of anatomy there are many other areas in which this technology has been implemented (Juanes et al., 1996). At the university of California, a system of anatomical teaching has been implemented in which multimedia resources and virtual reality are combined through information obtained from the Visible Human Porject of the National Library of Medicine (Hoffman and Murray, 1999).

Experimental multimedia work groups (task forces) have been set up with the participation of Medical students over a five-year period. The program includes all types of audioveisual media with computer-assisted instructions and a series of tutored sessions, without the use of text books of practicals for dissection. A comparative study was carried out between those students and others who received traditional teaching and it was concluded that the levels reached by both groups were very similar.

At the University of Natal (S. Africa) a study was conducted to assess the efficiency of a multimedia program for learning histology. The perception of the students was fairly positive and the multimedia approach did not affect their final scores in a negative fashion.

A prototype of a text book as a bridge between medical technology and basic teaching has been developed. It combines the most innovating techniques in imaging with a multimedia program for the teaching of anatomy. The program includes text, images, animations and three-dimensional reconstructions. The aim is to create a stimulating enviroment that will foster learning through interactive experiences. It is thus a new education system that promises to play a very relevant role as an alternative educational method in forthcoming years.

The ongoing advances in technology have enabled the development of virtual reality programs that allow users to perceive and interact in three-dimensional images. Stereoscopic images are merged with dissection imagery. These images, together with digital narration, are organised within an interactive multimedia programm (Trelease, 1998).

Another advantage of multimedia programs is the independence of students and instructors through distance learning. Yet another is the possibility of synchronic communication despite the distance between the two or more interacting parties. It is also possible to communicate with libraries, departments of anatomy or practicals rooms through the Internet.

At the University of Ulster (N. Ireland) a multimedia program has been developed for psychophysiological integration consisting of high-resoluion colour images that are presented to a subject through a stimulus program, with a data acquisition system that collects information from the subject (McCullagh et al., 1999).

At the Hanover Medical School in Germany an innovative system has been set up that involves the interactive use of multimedia for health professionals and patients. The rapid development of multimedia and their applications requires a reorganisation of our traditional planning and structuring.

The area of telecommunications (satellites, cables,…) facilitates communication and medical knowledge regardless of location. This development requires professional teams able to ensure that medical knowledge will be available in different multimedia forms, such as distance publishing, distance consulting, teleconferences, and distance learning. This adaptation of medical practice to the new technologies will become even more important in the future (Matthies et al., 1999).

At the University of Shimare (Japan), a system has been developed to organise medical knowledge and structure services that are useful for clinical education and practice. The system comprises integrated information about the patient's clinical history and of the images and data required for appropriate medical decisions to be made (Yamamoto et al., 1998).

The University of Philadelphia (U.S.A) has a computerised neuroanatomy laboratory for its medical students. The neuroanatomical sections were photographed and digitised and, using a multimedia system, a computerised atlas was compiled. To check the efficiency of this computerised laboratory, the students who used this method were compared with those following the traditional method. Both teachers and students agreed that the computerised system is an effective substitute for traditional teaching and that it favours integration between the students and group learning (Haux et al., 1998).

The University of Temple (Texas, U.S.A.) has developed an informatic system of Neuroanatomy as a substitute for traditional classes about microscopy. Those involved have concluded that this methodology favours both integration among students and their actual individual learning processes. (Jakobovits and Brinkley, 1997).

Yet another new advance in anatomical knowledge arose from the provision by the *National Library of Medicine* of a collection of serial anatomical images from a cadaver through the *Visible Human Project*.

Origins of the *Visible Human Project*

The *Visible Human Project* (VHP) was fruit of a long-term strategy planned in 1986 by the *National Library of Medicine (NLM) in Bethesda, Maryland, U.S.A.* (Figure 1) and aimed at complementing the library services in the *NLM* with libraries of digital images, distributed across high-speed networks and through high-capacity storage systems. As expected, those involved foresaw the increasing importance and dissemination of images represented electronically in clinical medicine and biomedical research. As a result of the deliberations of the specialists in medical education, it was recommended that the *NLM* should investigate in a direct and systematic fashion the technical requirements and viability of setting up a library of biomedical images (Akerman, 1991, 1998; Akerman et al., 1995, 2001).

At the start of 1989, under the direction of the *Board of Regents*, an ad hoc plan was put forwards to explore in depth the role of the *NLM* in the rapidly changing field of electronic imaging.

After much debate, it was recommended that the NLM should begin a first project consisting in constructing a library of digital images of complete volumetric data that will represent a normal male and a normal female human being. This project should include digitised photographic images of cryosections, digital images derived form computerised tomography and digital magnetic resonance images from cadavers. Thus, the first aim of the *VHP* was born: the acquisition of transverse sections at intervals of 1 mm in CT, MR and cryosections of the cadavers of a man and of a woman considered to be normal. The different sections of each of the three modalities were recorded (synchronised) with the rest. The contract for the acquisition of these images based on pixels was won in August 1991 by the University of Colorado at Denver, the main investigators being Dr. Victor M. Spitzer and Dr. David G. Whitlock.

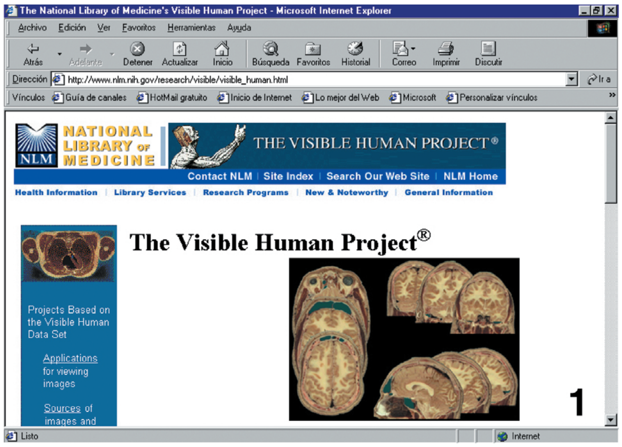
After its development, the *VHP* has been addressed in hundreds of articles in newspapers, news bulletins and medical journals, and also on the radio and television throughout the world.

Procedure for collecting anatomical images

After a two-year search for the cadaver of a man that would be appropriate for the project, that of a man of 39 was found; the man had been condemned to death for murder and donated his body to science. Once the cadaver had been obtained, it was scanned from head to foot using MR and CT. Following this, the cadaver was placed in a gelatin block and frozen at -160ºF, and then scanned again using CT, obtaining ultrathin sections of the frozen block using a special machine. Complete dissection of the cadaver took 10 months. Axial MR sections were obtained of the head and neck and longitudinal sections of the rest of the body at intervals of 4mm; axial CT sections examining the whole body at intervals of 1 mm and axial anatomical images at intervals of 1 mm (coinciding with the CT sections) were obtained.

In the case of the woman, the data were taken from a lady of 59, a resident of Maryland, who donated her body to science. The CT data obtained in life were obtained at different resolution in each section, but unlike the case of the man they were obtained every 0.3 mm.

The axial anatomical images from the man were obtained at a resolution of 1048 x 1216 pixels x 24 bits of colour per pixel, with a separation between sections of 1 mm and coinciding with the images obtained in CT. There is a total of 1871 axial sections, each with an approximate



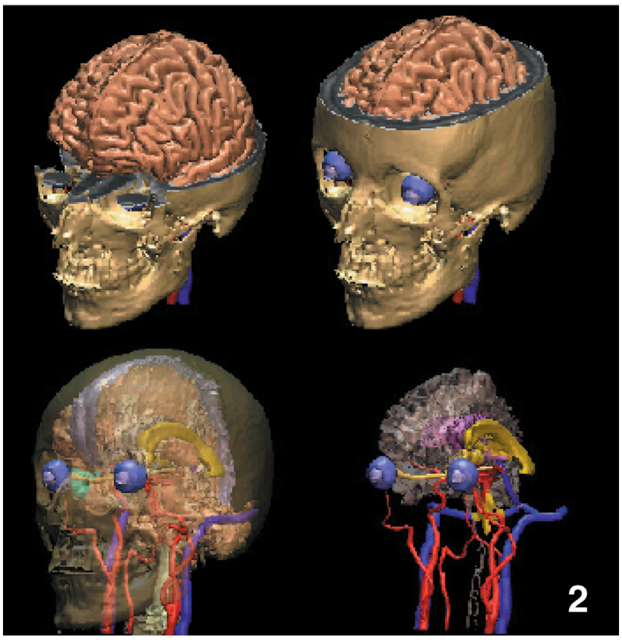


Fig. 1.- Visualisation of the access screen to the NLM, from where one can access the VHP.

Fig. 2.- Examples of images generated by the Voxel-Man project, developed by us from sections from the VHP.

size of 7.5 megabytes, and hence 15 gigabytes for the whole set of data corresponding to the man.

The data from the woman have the same characteristics as above, with the exception that the sections were obtained at a distance of 0.3 mm instead of 1mm. This difference in the distance between sections means that more than 5000 axial anatomical images were obtained. The change in the distance between sections means that they coincide with the pixel resolution of 0.3 mm, allowing investigators interested in three-dimensional reconstructions to work with cubic voxels.

In both the man and the woman, there are two types of CT sections: one type was obtained with the cadaver frozen and the other with the cadaver in the fresh state, the latter being better because they show better contrast among the different tissues. Each section is stored in a single file, compressed in Unix format and, once decompressed, affords a native image of 512 x 512 pixels zise, with a depth of 16 bits/pixel. In comparison with the MR sections, and in view of the 1 mm distance between sections, the use of CT sections makes it especially easy to separation the soft tissues from air and from bone together with the possibility of creating three-dimensional models of acceptable quality.

There are 1734 CT sections taken in life, which occupy approximately 480 megabytes of disk storage space (compressed).

Each image has a heading of 2416 bytes in the Genesis format from General Electric where information that is very important for the correct use of the sections is stored, such as the size of the pixels, the distance between sections or the order of acquisition of the sections (which is very important for suitably maintaining the left/right correspondence and which in the case of CT sections in the fresh state were acquired from top to bottom).

The resulting data set is formed of axial MR images of the head and neck and longitudinal sections of the rest of the body at intervals of 4 mm, enhanced in T1, T2 and proton density. The MR images have a size of 256 x 256 pixels and 12 bits of pixel depth. The distance between sections, however, does not permit the creation of quality three-dimensional models.

Applications of the *VHP*

Once the sections have been obtained, they can be used for a broad spectrum of applications. Below we describe some of the most relevant ones.

Anatomical atlas by sections.

This is possibly the most common type of application because it is the first obligatory step that all users must perform upon constructing a *VHP* application. The simplest step is the collection of sagittal and coronal sections from axial sections by the so-called re-slicing technique.

Once the sections have been processed and the sections of interest have been obtained, all types of applications can be created. The simplest use is the application for an anatomical atlas.

Reconstruction of three-dimensional models by rendering

In the development of the best interactive three-dimensional atlases of Human Anatomy, a special role has been played by the database of the VHP, through which it is possible to create three-dimensional models from images of transverse sections (Kerr et al., 1996).

The relationships between structure and function have been crucial along history to understand health and disease. For many centuries, the basis of medical studies lay in the illustrations originally made during the Middle Ages. Accordingly, the interpretation and learning of anatomical data were limited because these were in the form of two-dimensional ilustrations (Akerman, 1999). Indeed, one of the most difficult learning tasks in gross anatomy was to understand the three-dimensional spatial relationships of the different anatomical structures. Thus, for many years medical professionals and IT scientists wished to create pseudo-real three-dimensional structures of human organs (Temkin et al., 2002).

The advent of digital computers allowed scientists to obtain, store, manipulate, and edit complete images, thereby allowing the compilation of 3D- interactive atlases of human anatomy (Schubert et al., 1993; Toh et al., 1996; Vanier et Marsh, 1996, Whiten et al., 1998; Akerman, 1999). Their great utility in anatomical learning derives from the fact that they allow one, an interesting way to recognise organs and their structural and topographic structures (Spitzer et al., 1996; Slavin, 1997; Akerman, 1999; Temkin et al., 2002). The main advantages of comuterised anatomical atlases include the ability to support several interactive approaches related to the available information and anatomical education (Kang et al., 2000).

Direct interaction with anatomical structures aids their understanding and our knowledge of the spatial relationships they maintain with neighbouring structures.

One method used in reconstruction is rendering (Kerr et al., 1996). This technique permits the creation of 3D-models, where the textures assigned to each object may be solid colours (very useful for identifying and separating anatomical structures). It should be stressed that it is also possible to assign semitransparent textures, among others.

Another commonly used method in the collection of 3D reconstructions is volumetric reconstruction (visualisation). In this case the colours or textures assigned to the objects are obtained directly from the values of each of the *voxels* that form the 3D object. This technique, which is very complicated and difficult to achieve owing to the huge amont of calculations involved, enables the creation of realistic reconstructions and, more importantly, the possibility of seeing structures located inside a given section, unlike the situation in rendering, where only the surface of the object of interest can be obtained.

It is also possible to integrate both types of reconstructions (rendered and volumetric) in such a way that the teaching aim is reinforced; that is, it is possible to obtain a photorealistic 3D structure and, on this, assign an unreal colour to an object (e.g., arteries, a given muscle, etc).

Temkin et al (2002) described a system of three-dimensional virtual anatomy based on web sites that includes an interface for navigating through the VH database, the construction of volumetric structures, and the ability to "touch" those geometric structures with a *haptic Phantom* device. It also includes a dynamic interface for the user's voice that allows interaction with the computer.

Surgical simulations and training.

The usual training received by surgeons in surgical techniques has to date been based on the use of cadavers, live animals, or real surgical interventions under the guidance of experts, all of which pose ethical problems owing to the scarcity of subjects and the reduced number of interventions in certain pathologies. Hence the advantage of the systems of surgical simulation as compared with traditional training methods since they allow a reduction in the costs of the material of subjects used; they provide experience to the surgeon in a broader spectrum of pathologies and complications; they allow surgical interventions to be repeated as many times as is necessary until they have been correctly learned; they improve procedures, and they allow operations to be planned before the real procedure is carried out (Muller et al., 1997).

Structurally, a surgical simulation system has two subsystems: the interface subsystem of the surgeon, whose aim is to provide the user with a realistic visualisation of the computerised reconstruction of the internal organs of interest in the simulation, such that it combines advanced computer graphics techniques (advanced model of complex geometry to obtain a realistic 3D visualisation and deformable models for incorporating physical properties to 3D tissues generated by the computer) and advanced visualisation techniques (techniques of virtual reality and of three-dimensional visualisation). The second subsystem is that of sensors, composed of a set of "haptic" devices which must imitate the devices used by surgeons in real procedures in the most realistic form possible.

The greatest difficulties or restrictive requirements lie precisely in the simulated environment in which the organs present must behave as they would in reality when subjected to forces, cutting or suturing (realistic physical models) so that the organs will be visualised in the most realistic way possible (realistic geometric models). Accordingly, most models available on the market or developed by research teams have eliminated the physical aspect of the organ models by limiting the interaction merely to detecting contacts between rigid objects (Geiger and Kikinis, 1995; Ziegler et al., 1995) or incorporating elastic physical characteristics (Cotin et al., 1996; Bro-Nielsen, 1996; Delingette, 1998). Despite these limitations, many research groups continue to devote their efforts to developing this type of simulator, among which outstanding are *Laparoscopic Cholocystectomy* developed by Michael Downes et al. (1997) at the University of California; *Laparoscopic Simulator*, developed by Basdogan et al. (1998) at the Laboratory for Human and Machine Haptics of the University of Missouri-Columbia; *Virtual Endoscopy* (Robb, 2000); *Hepatic Surgery Simulator* developed by Cotin et al. (1996) at the INRIA Research Centre in France; *Anastomosis Simulator* developed by Boston Dynamics Inc, or the Arthroscopic Knee Surgery Simulator developed by Gibson et al. (1997) at the ERL Research Centre. In Spain, too, there are simulators being developed at the Polytechnic University of Valencia for training in advanced surgery.

A more advanced use of *VHP* sections is the creation of simulations of a given diagnostic-therapeutic procedure (interventionalist radiology, virtual endoscopies, etc) or biological process. In general, to implement these types of project it is necessary to employ more than on type of *VHP* data. Thus, for example, a usual procedure is to use anatomical sections (anatomical information) together with CT sections (information about the attenuation coefficient of X-rays on passing through different tissues). This is possible thanks to the spatial synchronisation between sections.

Cadaver dissection is an intense and humanising experience for students but it may involve some risks due to the methods employed for embalming (relatively toxic substances are used) and it also has the drawback that some of the characteristics of living specimens, such as the colour of organs or the texture and sensory sensations gained when they are manipulated, are missing. Accordingly, as proposed by some authors (Spitzer and Whitlock, 1998) the use of a human simulator with "tactile sensors" may palliate these differences and heighten the experience obtained with dissection. For this, it is also necessary to improve the information that can be obtained from the *VHP* database concerning the texture and colour of organs. In this sense, Kerr et al. (2000) have developed a method for modifying the colour texture generated from volumetric data.

From *VHP* sections, and thanks to the fact that these have constant thicknesses and that they have been collected at constant distances, it is possible to create an environment that can help physicians in both pre-operative and post-operative surgical planning.

Computer-assisted surgery (CAS) is a recently developed field of technology that attempts to develop and supply tools to surgeons that will be of use in diagnosis and in the planning and performance of surgical procedures (Adams et al., 1990). It is applied in a fairly large number of medical specialities (Taylor et al., 1996), although one where it finds greatest use is in neurosurgery since this is extremely demanding as regards precision in the surgical approach: tiny errors lead to severe consequences and irreparable damage.

Traditional neurosurgery was a qualitative technical exercise that involved manual techniques based on the hand-eye coordination of the surgeon, using data provided by projective radiographic techniques and clinical signs deduced from neurological findings, but leading to long and complicated interventions with important sequellae for patients. Current neurosurgery, however, is constantly improving its procedures on the basis of technological advances in neuroimaging. These have permitted the development of computer-assisted neurosurgical techniques. In today's procedures, one begins with the *data acquisition phase* to actually define the pathological lesion to be addressed and its spatial relationship with the normal structures that must be preserved. For this, diagnostic imaging techniques such as CT, MR, PET, SPECT, digital subtraction angiography, etc are used. Once the lesion has been diagnosed, the next step is *surgical planning,* to define the safest approach to be used by the surgeon. For this, too, two-dimensional neuroradiological images are used but here the clinician must make a three-dimensional composition of the patient's anatomy and of the location of the lesion based on experience, which is an arduous task. Once the planning step has been completed, the patient is ready for surgery in the operating theatre, and normally stereotactic headphones are used to locate the cerebral coordinate where the lesion is located.

With CAS, during the information acquisition step digital images are generated and collected. In the planning stage, the physicians must have available a series of tools that will afford them the possibility of obtaining an *advanced visualisation of medical images* so that they can observe several images at the same time, or different planes of section oriented in any spatial direction, or the presence of filters to improve the image; *image segmentation*, which as far as possible must be carried out automatically or semiautomatically, so that they can recognise and label the different tissues and relevant anatomical structures in each image; *the fusion of images* with complementary information, and *three-dimensional visualisation of images* (segmented), for which tools for three-dimensional visualisation by surface reconstruction and for volumetric visualization (volume rendering) are required (Cazorla et al., 1995; Alcañiz et al., 2000).

In the intervention step, the most important system of CAS is the surgical navigator, which essentially consists of a three-dimensional digitiser that provides -in real time- the 3D coordinates of the surgical instrument being used over images obtained in the planning step on a computer screen (Alcañiz et al., 2000).

From the high-resolution data of the *VHP* and from the advances made in recent years in the fields of segmenting, navigation, simulation, modelling and educational methodology, a fairly large body of computerised anatomical atlases has been generated However, in most cases stress is placed on study of the central nervous system and its main visceral organs (Toh et al., 1996; Schiemann et al., 2000; Pommert et al., 2001).

Another important field in the development of interactive 3D atlases has been the ontogenic one, with the construction of important atlases of embryonic organs (Whiten et al., 1998).

Regarding the locomotor apparatus, fewer computerised anatomical atlases have been compiled than in the case of brain structures, although those that are available are very interesting and offer important contributions to the development of this type of scientific enquiry (Chan et al., 1991; Lorenson, 1995; Tiede et al., 1996). Kang et al. (2000) compiled a three-dimensional anatomical atlas of musculo-skeletal elements of the lower limbs based on data from the *Visible Human Male* that support several interactive activities, among them rotation, removal of objects, highlighting with artificial colours, the collection of arbitrary sections, transparent views, and follow-up via two-dimensional images of transverse, coronal and sagittal sections with information about labelling and segmentation.

One of the major achievements of this work was semiautomatic segmentation carrying out the approach with intelligent scissors and interpolation based on shape. These techniques minimise the tedious work involved in segmentation and labelling. Also, by binary volumetric rendering it is possible to reconstruct anatomical structures in very few seconds from two-dimensional serial sections, thus permitting manipulation in real time of the computerised atlas.

IT developments in WEB CD-ROM supports on the Internet based on the *VHP*

The market now offers a large variety of biomedical software on CD-ROMs that permits volumetric visualisations using *VHP* images. There are also many IT applications that handle these *VHP* sections that can be found on the Internet (North et al., 1996).

According to the report entitled Visible Human Project Conference Proceedings (1996), the editorial report of Slavin (1997) and the papers by Spitzer and Whitlock (1998) and Akerman (1999), treatment of the images from the *VHP* database has passed through several stages. In the first, only images from the database were available, through navigation interfaces. Examples are the CD disc and laser disc entitled "*Complete Visible Human Male* (1995) and *Visible Human Explorer* (1997), from Anatomical Visualization Inc; *Female Visible Human* from Research Systems Inc (1997). A second stage saw the incorporation of labels with the nomenclature of the anatomical structures (Cross-Sectional Anatomy Tutor in the CD, by Jones and Barlett, 1998). The third phase featured the segmentation and complete classification of the images offered in the database (*Segmented Visible Human,* 1997, and *Virtual Human,* 1997, from Gold Standard Media Inc).

There was also a significant difference in the presentation and manipulation of publications deriving from the VHP, since the first works were usually based on computers while later ones were based on Web sites. Thus, in the first instance several systems were developed that offered tools for teaching through surface-based models. Among them the Anatomy Browser (Golland et al., 1999), which used pre-rendered images; the Anatomic Visualizer (Hoffman and Murray, 1999), which allows one to plan lessons from anatomical models, or the Voxel Man Project, with sophisticated products for the teaching of anatomy on the basis of three-dimensional images, although with limited interactivity. Among the main systems based on Web sites that use the VH database are the *Visible Human Browsers* from the University of Michigan, which supplies a navigator for basic VH images but does not offer anatomical information, merely separating the sections into 5 main regions (head and neck, chest and abdomen, pelvis, upper, and lower limb); the *Cross-sectional Anatomy* of Gold Standard Multimedia, which can be visualised through a plug-in compatible with the Web browser. This system allows users to highlight structures on a section but limits use to working or visualising axial sections. The *Analine* from the NLM has an on-line anatomical browser and two anatomical databases; one for on-line searches and the other for use after downloading. The anatomical browser provides pre-rendered images of surface-based three-dimensional models that users can employ to navigate through the chest. The anatomical database allows users to search by name for images of body structures with links to files that can be downloaded and visualised using the VHDdisplay software from the NLM. These files contain rendered (volumetric) anatomical images, blocks of sections of segmented images and "byte masks" for the segmented anatomical structures. The *Visor Visible Human* from the University of Adelaide is adapted for visualising images of VH sections with axial, coronal and sagittal orientations.

This prototype offers visualisation in real time and tactile sensation (haptic feedback), thereby allowing, for example, the simulation of surgical incisions in which the user, while cutting, feels the texture of the tissues through which the scalpel is passing, or the practice of anaesthetic blockade, arthrocentesis, radial keratotomy, etc. With this, students or physicians can learn the skills and coordination necessary to perform such procedures in real patients but at no risk.

One of the IT programs that has been very popular among anatomists is the so-called VOXEL-MAN/brain and VOXEL-MAN/skull, which are the fruit of a research project aimed at representing the morphology and function of the human body by new techniques based on computer use (Schubert et al., 1997; Pflesser et al., 2001).

The VOXEL-MAN/brain is a model obtained from MR sections, acquired with a spatial resolution of 1 mm. Additionally, it includes images from the Visible Human collection. VOXEL-MAN/skull is derived from CT images, obtained at a spatial resolution of 1 mm.

VOXEL-MAN is based on a "virtual body" model (by "space-filling") that permits many different types of exploration to be made. It is an ideal tool for teaching and the study of anatomy and radiological anatomy (IMDM, Hamburg, 1998).

The basis of three-dimensional atlases of the brain and skull is provided by 10 million voxels ($1mm^3$).

The hardware and software configuration required for its visualization and running comprises a UNIX or PC LINUX (Pentium or above with a LINUX operative system) work station. It requires more than 96 MB of main memory. The user interface is OSF/Motif. The space necessary on the hard drive is approximately 600 MB, 200 MB or 300 MB of swap space being recommended. For visualisation, a high-resolution colour monitor is recommended.

VOXEL-MAN/Brain offers the possibility of creating animations in Quick Time and taking measurements of lengths, etc. It also includes basic operations used to explore (REMOVE, PAINT, ANNOTATE) or compose (ADD,…) a scene, in the SERVICES menu.

It also has windows through which the virtual model can also be visualized on three radiological planes (transverse, coronal, sagittal). Among other possibilities, it is possible to access a single domain, such as morphology, functional anatomy, vessels, etc, as shown in figure 2.

It is possible to carry out dissection planes, through cadaver slices from the *VHP*: selected parts of these sections are included in several VOXEL-MAN atlases as additional reference. However, since different bodies are involved, matching is not perfect.

This IT application has been used by us in the teaching of anatomy (Juanes et al., 1999b). As an example, we offer some images generated by us with the Voxel Man application (Fig. 2).

The Internet also has different freely accessible programs for interactive study of aspects related to anatomy. Of interest in this sense is *"The NPA/COLDA Visible Human Viewer"* from the University of Syracuse (Yuh-Jye Chang et al., 1997), consisting of an applet in Javascript that allows the extraction of orthogonal anatomical sections from data from the *Visible Human Male (The National Library of Medicine. NLM-, 1986).*

Currently, at the same university, an interface in VRML is being developed to select only axial sections from a sliding plane on a model of the human body (Markowski and Odcikin-Ozdemir, 1999).

At the University of Maryland, North et al. (1996) developed a prototype program to visualise a miniaturised volume, generated from the same NLM collection, which allows users to locate a level of interest and automatically obtain the corresponding anatomical image at maximum resolution. This application is only operative on Sun graphics stations with at least 30 MB of free drive space. The "*Whole Brain Atlas*" project from the Harvard Medical School (Johnson and Becker, 1999) is based on a Java interface that generates axial sections obtained, in this case, by brain imaging.

There is also a tutorial program network, also freely available, based mainly on the sequential consultation of images labelled with the main neuroanatomical structures. Of great interest in this sense are the tutorials developed by the Tulane School of Medicine (Bookstein, 1994) or those of the Loyola University of Chicago (Castro, 1999).

From the thousands of images present in the VHP (corresponding to the man and the woman) and the thousands or individual and collective licenses, conceded by the NLM destined to private and public enterprises in more than 30 countries, the database has become the compilation of digital human anatomy most used world-wide for different ends, although mainly for teaching. Although VH images enable visualisation of the body, it is data segmentation that provides structural information for each pixel. The combination of colour information, at pixel level, of the images and the structural information of the segmented data are the basis for the creation of virtual body structures that may be based on surfaces or on volumes. Surface virtual body structures are three-dimensional geometric models corresponding to the external surface of a given anatomical structure and they use polygons to define the surface of the model by generators of virtual structures that allow the user to select the anatomical structures from an axial section, a body region or an anatomical system and to create a surface-based three-dimensional model (Temkin et al., 2002). In volumetric virtual body structures, both the external structures and all the internal substructures included in a specific volume of interest (voxel) must be defined.

Future perspectives

The new technologies, headed by graphic simulation, are gradually beginning to come into the limelight in the field of medicine. Computer- assisted interventions are now starting to be a reality in the field of surgery and although these techniques are still in their infancy it is clear that their evolution is progressive and very rapid.

The possibility of generating very realistic 3D images allows users to become immersed in the synthetic worlds generated by computers and to manipulate objects that reside only in computer memories. Interactivity, which can be carried out within a virtual environment, totally activates the senses inside a simulated world.

It seems clear that we are heading towards a future in which such systems for the virtual visualization of body structures will impose themselves on our understanding and teaching of anatomy and, indeed, the list of new applications is growing steadily. These 3D simulation systems allow users to perform different tests and experiments, thereby avoiding the high costs, and in certain cases the risks, of certain tasks.

Undoubtedly, the capacity that a computer must have to be able to generate a virtual situation must be very large. Accordingly, PCs are still some way from being able to offer such possibilities. Machines with enormous computing power are required so that they can generate, in real, time, our real-life environment.

It is equally clear that a computer can never replace direct experience but in many instances, owing to the impossibility of accessing such experiences, computer simulation may offer an extremely positive complementary tool. We believe that this, which in our country is only at the dawn of its possibilities, will in the future become an anchor point in the teaching of medicine and will surely change the course of our teaching systems.

Some manufacturers, such as Silicon Graphics, use powerful programming tools such as the LINUX operative system. The devices built by this company devote most resources to the graphic representation system, integrated by virtual stereoscopic images.

Silicon Graphics is at the forefront of computer-designed graphics. The devices are used by most companies devoted to infographics and the company is the undoubted leader in graphics-oriented work stations.

To generate good anatomical images in three dimensions it is necessary to have sophisticated hardware and software so that a good graphic environment can be configured between both. Accordingly, a good computerized system must have the synthetic capacity to generate and reproduce images in three-dimensional format and in real time. Also, the system must be interactive with users, allowing them to vary the visual scenes offered (rotations, sections etc).

Perspective and the appearance of depth in images are crucial for creating synthetic images as close as possible to true life. Thus, the images must always be three-dimensional, allowing the simulation of different optical effects.

The "*Virtual Brain*" Project of the university of Barcelona (Prats-Galino et al., 2000, 2001) is one of the first attempts to develop a platform for the visualisation of neuroanatomical structures in three dimensions through a free navigation system (Figs 3-8). The interface of the application is programmed in Java and controls the behaviour deriving from interactions of the user with the VRML (Virtual Reality Modelling Language) scene, allowing real-time manipulation of 3D models that represent deep brain structures of clinico-functional interest and of sections on the three orthogonal planes of the head, obtained from the NLM collection. The program only requires an Internet navigator (Netscape) compatible with the plug-in Cosmo Player (Silicon Graphics). An operative version of this can be found at: *http://www.med.ub.es/-aprats/vbrain*.

Also of great interest are recent attempts to develop specific computerised systems of the brain in order to access information stored in databases through the so-called geographic information systems (Juanes et al., 1999a, 2001).

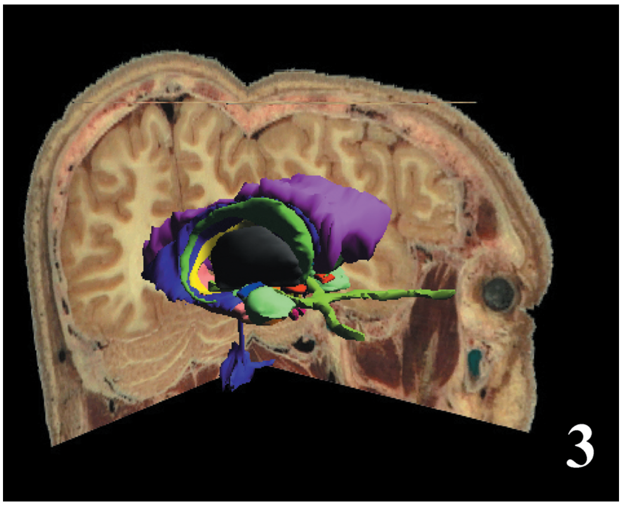
The current line of work using the VHP includes the application of material, able to give the images the properties closest to the anatomy of the living being. In this sense, at the pioneer centre of the VHP, the Center for Human Simulation at the University of Colorado (USA), progress has advanced from segmentation and complete classification of the VH male database to the recognition and labelling of anatomical structures, to the application of filters to obtain voxels to which Lorenson algorithms were applied and then three-dimensional rendering on specialised graphic machines and to the application of virtual reality techniques (Reining, 1996; Reining et al., 1996). With this, a prototype has been constructed for the simulation of medical procedures that can be controlled by the user, with three-dimensional presentations, and that allows users to feel the anatomical manoeuvres carried out during the exploration and the practising of interventions through the instruments used in daily clinical practice (Spitzer and Whitlock, 1998).

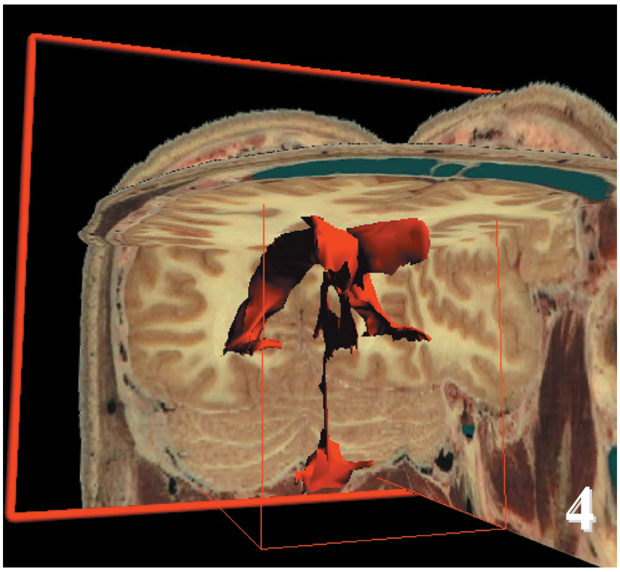
Now that the data collection phase of the VHP has been completed, another phase-segmentation, classification, and 3D reconstruction of the structures has been initiated. This phase includes the labelling of structures and the relating of each object to the other objects from its own section and in adjacent sections. The data files of the VHP are designed to serve as a common reference point for the study of human anatomy, as a repertoire of data accessible by the public that can be used in the development of algorithms and as a test basis for the construction of image libraries that can be accessed through communications networks.

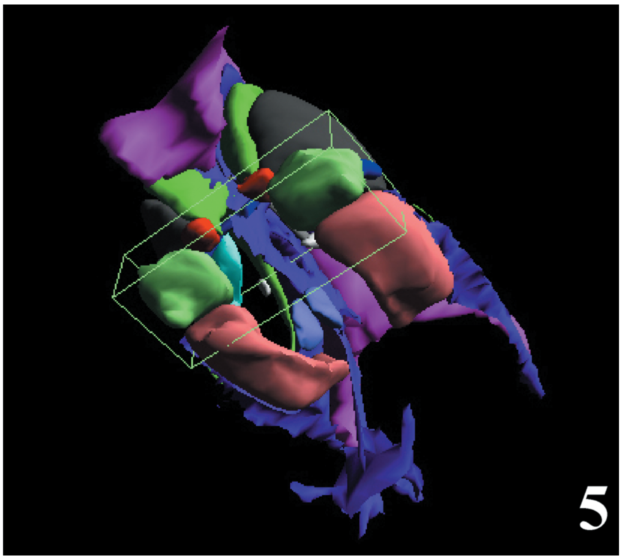
The main problems are found in the development of methods that allow one to integrate the structural-anatomical data based on images with the functional-physiological data based on text. This is the goal of the project: the transparent integration of digital structural and anatomical images with functional and physiological knowledge.

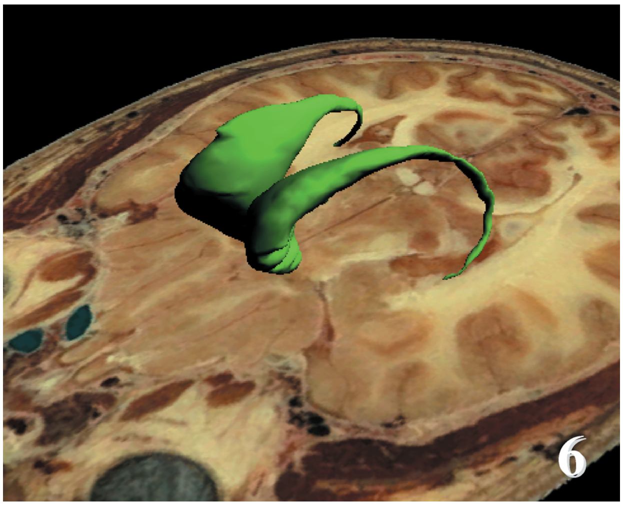
Recent years have seen the incorporation of updated anatomical techniques (from conventional radiology to the latest novelties, such as multisection helicoidal CT) together with image treatment methods for obtaining 3D views on both the surface and the inside of a virtual support.

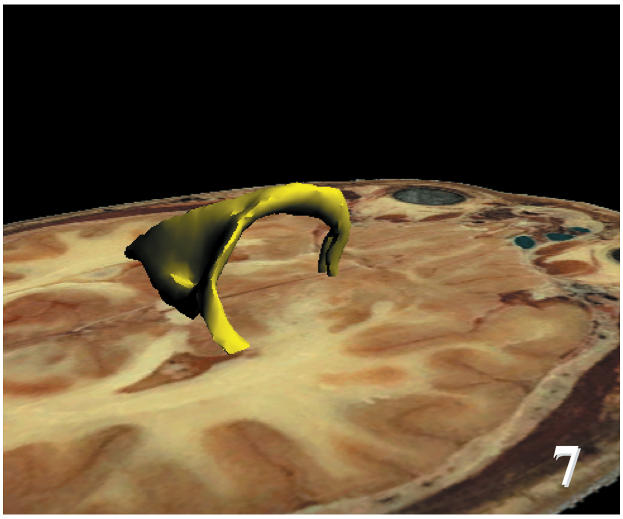
Despite the advances made, the achievements would only represent one of the goals of the larger aim of the VHP, which is to construct a virtual human body for the simulation of physiological and pathological processes that will allow assays of different clinical procedures for diagnostic and therapeutic ends.

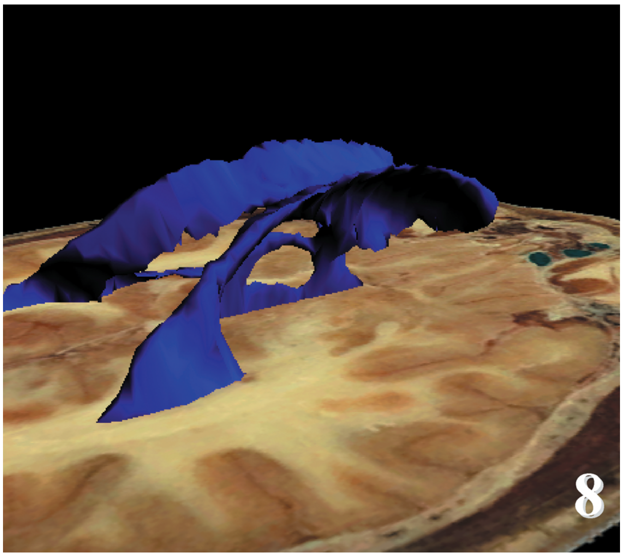












Figs. 3-8.- *Images from the "Virtual Brain" IT application of the University of Barcelona, elaborated by the authors of this article.*
Fig. 3.- Visualisation of brain structures in three dimensions, with two reference sections (coronal and sagittal), from the VHP.
Fig. 4.- Visualisation of ventricular volume in three dimensions, with three reference anatomical sections.
Fig. 5.- Isolated three-dimensional brain structures, with their neighbouring relationships, in different ranges of colour selected freely by the user and the possibility of observing them in different spatial rotations.
Fig. 6.- Image showing the caudate nucleus in three dimensions, on an axial section from the VHP as anatomical reference of its location.
Fig. 7.- Image showing the fornix in three dimensions on an axial section from the VHP as anatomical reference of its location.
Fig. 8.- Image showing the cast of the brain ventricles in three dimensions embedded, on an axial section from the VHP as an anatomical reference for its location.

The enormous development of IT media has allowed traditional working methods to be adapted to the new technological conditions of our social environment. One of the most recent novelties in the sphere of medicine, and in particular in anatomy and surgery, are the infographic techniques, which promise to change our way of thinking as regards teaching systems in very few years, as is now being done in the most technologically advanced countries.

With the development of graphic representation systems, the data and control of virtual environments are no longer accomplished in numerical form and are now done with control devices.

In recent years, increasing numbers of advanced multimedia applications have been developed for interactive study in many disciplines (Prats-Galino et al., 2000). In the particular field of neuronatomy, two types of commercial programs are available:

–"*Linear*" programs, with abundant material in the form of images and whose information can be accessed through a thematic index. These contain static anatomical and radiological images, animations and videos, in an electronic atlas format (Abrahams, 1998; Viaño et al., 1999).

–"*Free navigation*" programs, in which access to the information is flexible, such as performing dissections in real time (Olson, 1997), study of sectional anatomy (Bulling et al., 1999), or the use of 3D synthetic models for preset views (Hirsh and Kramer, 1999). Recently the *Institute of Mathematics and Computer Science in Medicine* (University of Hamburg) has developed a multimedia program for the learning of morphology and functional anatomy of the human brain with 41 3D QuickTime VR scenes that can be explored interactively.

The continuing technological advance and the incorporation of these IT procedures open new doors into the field of anatomy, above all in the teaching field. We believe that these IT developments will in the future form the basis of a major means of communication between students and teachers, offering an alternative to the traditional methods currently used in Medicine.

ACKNOWLEDGEMENTS

This work was supported by grants of Departament d´Universitats, Recerca i Societat de la Informació (Generalitat de Catalunya, 233 MQD) and the Gabinet d´Avaluació i Innovació Universitària (Universitat de Barcelona, 2003PID-UB/26).

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The international scientific community has used images from the VHP in many types of applications. Below, we offer some that have had the greatest impact in the biomedical field, including their electronic addresses.

http://www.nlm.nih.gov/research/visible/visible_human.html.

http://visiblehuman.epfl.ch/

http://visiblep.com

http://www.npac.syr.edu/ projects/visibleHuman/ html

http://www.supercomp.org/sc95/proceedings/620_KMIL/SC95.HTM.

http://www.mcl.tulane.edu/ student/1997/ kenb/neuroanatomy/readme_neuro.html

http://www.dhpc.adelaide.edu.au/projects/vishuman/.

http://www.npac.syr.edu/ projects/ 3Dvisiblehuman/ VRML/ VRML2.0/ MEDVIS/

http://www.cs.umd.edu/projects/hcil/Research/1995/vhe.html.

http://www.meddean.luc.edu/lumen/MedEd/GrossAnatomy/cross_section/index.html

http://www.cs.umd.edu/projects/hcil/Research/1995/vhp/dl96/vhe_dl96.html.

http://www.cs.umd.edu/hcil/visible-human/vhe.shtml

http://www.ciemed.nus.edu.sg/projects/av/av.shtml

http://www.dal.qut.edu.au/DALhome.html

http://www.dmsv.med.umich.edu/research.html

http://www.med.ub.es/~aprats/vbrain/

http://java.sun.com/aboutJava/index.html.

http://java.sun.com/applets/index.html.

http://java.sun.com/products/jdk/rmi/index.html.

http://www.uchsc.edu/sm/chs/browse/browse/htm

http://www.ncsa.uiuc.edu/SDG/Software/Habanero/.

http://www.npac.syr.edu/projects/tango/.

http://www.dhpc.adelaide.edu.au/projects/ vishuman/

http://www.uke.uni-hamburg.de/institute/imdm/idv/gallery

http://www.uni-mainz.de/FB/Medizin/Anatomie/workshop/engleWelcome.html

http://summit-3.Stanford.EDU/vishum

http://www.crd.ge.com/esl/cgsp/projects/vm/

http://www.crd.ge.com/cgi-bin/vw.pl

http://www.madsci.org/-lynn/VH/tour.html

http://www.mmms.com/dh/default.htm