

Digital Anatomy for the 21st Century: Creating the Virtual Patient

Donald R. Hilbelink, University of South Florida, Tampa, FL

The development of a virtual patient is highly dependent upon the availability of both a high level of computing capability and a detailed set of data from which to construct the virtual model. During the past three decades great strides have been made in both of these areas. We are entering an era in which virtual patients will become not only useful but essential for the training and practice of modern medicine.

Advances in Computer Technology

The late 1970's to early 1980's witnessed the release of the Apple II desktop computer (1977); the first portable computer, the Osborne 1, that weighed 24 pounds and featured a 5-inch display, 64 kilobytes of memory, a modem, and two 5 ¼ floppy disk drives (1981); and the IBM PC-AT (1984), based on the Intel 80286 chip, featuring a high-density 1.2-megabyte, 5 1/4-inch floppy disk and the Microsoft Disk Operating System (MS-DOS). The workhorse of the research computers was the VAX 11/780 from Digital Equipment Corp. which was able to address up to 4.3 gigabytes of virtual memory. In 1984 the object-oriented programming language C++ was introduced providing greater ease and versatility in software development. By the late 1980's computer technology advanced to a point that computer simulation was first possible. In the late 1980's the concept of virtual reality became a hot topic. Silicon Graphics computers were optimized to maximize the features of computer-aided design software. Computer-generated 3-D environments were produced that allowed users interaction. One of the most successful of these endeavors was the flight simulators that are in common use today. Throughout the 1990's the number of simulations grew as did their sophistication. Simulations such as SimCity, allowed the user to create his own city with buildings, roads, and waterways. Basic services like health care and education and challenges in the form of natural disasters, airplane crashes, and monster attacks could be added to the simulation. By the late 1990's computer technology had advanced to the point that companies such as Reachin Technology (Stockholm, Sweden) and Immersion Technology (San Jose, California) began research and development of surgical simulation workstations. New societies such as Medicine Meets Virtual Reality (MMVR) were initiated where researchers could share research data and demonstrate state-of-the-art computer simulation devices.

Medical Imaging Technology

During the 1970's computed tomography (CT) and magnetic resonance imaging (MR) became a core component of clinical medicine. In 1975, Robert S. Ledley (Georgetown University) was granted a patent for a "diagnostic X-ray systems" also known as CAT-Scans. For the first, time detailed images could be obtained of the internal organization of the body by way of a series of two-dimensional slices. By imaging and looking at a series of these slices a doctor could tell not only if a tumor was present, but roughly how deep it was in the body. Initially these slices were no less than 3-5 mm apart. Advances in both computer and imaging technology during the past decade resulted in development of the advanced spiral (also called helical) CAT scanners which can now produce high resolution, contiguous, 1 mm slices through the body in a matter of seconds.

Magnetic resonance imaging (MRI) technology was not far behind the development of the CT scanner. A physics phenomenon, called nuclear magnetic resonance or NMR, was identified by Felix Bloch (Stanford) and Edward Purcell (Harvard) in the 1930's. With this technology magnetic fields and radio waves caused atoms to give off tiny radio signals. This led to the development of NMR spectroscopy which is still routinely used in laboratories around the world in the study of the composition of chemical compounds. By modifying the use of NMR technology, magnetic resonance (MR) imaging devices were developed for medical imaging. In 1970, Raymond Damadian (SUNY), reported that different kinds of animal tissue emit response signals that vary in length, and that cancerous tissue emits response signals that last much longer than non cancerous tissue. Less than two years later he filed his idea for using magnetic resonance imaging as a tool for medical diagnosis with the U.S. Patent Office, entitled "Apparatus and Method for Detecting Cancer in Tissue." A patent was granted in 1974. It was the world's first patent issued in the field of MRI. This work coupled with seminal experiments by Paul Lauterbur (SUNY) and Peter Mansfield (Nottingham, England), both of who received the Nobel Prize in Physiology and Medicine in 2003, culminated in the development of today's MR imaging technology. The medical use of magnetic resonance imaging developed rapidly. MR imaging equipment was first available at the beginning of the 1980s. By 2002, approximately 22,000 MRI scanners were in use worldwide, and more than 60 million MRI examinations were performed.

Virtual Cadavers

In order to produce a computed virtual human, a high resolution image data set from which to build the 3D morphology is essential. In 1989 the National Library of Medicine initiated the Visible Human Project (1-2). The intent of this project was to build a digital library of volumetric data representative of normal male and female anatomy. The first Visible Human data set was released in 1994. In addition to CT and MR images of a male specimen, 1,871 cross-sectional images were released in 24 bit color. Image dimensions of 2,048 pixels by 1,216 pixels with each pixel being 0.33 mm in size resulted in an image size of 7.5 megabytes which collectively produced an image data set of greater than 9 gigabytes. In 1994 this set of images exceeded the graphic display capabilities and the data storage capacity of most existing computers. In 1995, a Visible Human female image data set was released containing 5,189 images composing a data set approaching 40 gigabytes in size. Since the mid 1990's these image sets have proven to be invaluable resources in the development of computer-based virtual cadavers and patients. Through continued funding from the NLM, suites of visualization software toolkits have been developed allowing the user to build both 3D volumetric and surface models from the Visible Human Project image data. The results have been the development of education-based products such as the *Interactive Series of Human Anatomy* (Primal Pictures, London) and the *VH Dissector* (Touch of Life Technologies) for the teaching of human gross anatomy.

Virtual Human Anatomy Navigation System and a Three Dimensional Cartesian Coordinate System

Until recently it was not possible to objectively measure and statistically compare morphological features between individuals or patient populations. In 2005, a framework for a 3D Cartesian coordinate system for human anatomy was proposed (3). With this coordinate system, an exact 0,0,0 point is defined for all human beings. Using this coordinate system, it is

now possible to register volumetric image data in 3D space. Once registered, specific anatomical features such as the shape, size or position of a structure can be accurately and reproducibly measured in 3D space. This data can be used to follow morphological changes that take place during growth and development or to measure anatomical alterations that occur with aging or specific disease conditions. This system is resolution independent and lends itself to increasing detail and complexity as the resolution of medical imaging increases.

Virtual Patient

So where does this leave us in our pursuit of the development of a virtual patient? There is no doubt that medical imaging technology is at a point that it can provide us with relatively detailed morphological information of an individual patient. Medical imaging which has historically been a two dimensional technology is now evolving to routinely provide volumetric three dimensional data. Medical imaging researchers are now focusing on the development of scanning devices that capture multimodal (CT, MR & PET) data simultaneously. With development of these new devices the capture of structural and functional data for individual patients that is also registered in 3D space will be possible. This should provide us with confidence that virtual anatomical models of individual patients is not far away.

During recent years the research focus has shifted to an interest in developing not just accurate visual anatomical models but has broadened to include dynamic functional models that reflect the biological nature of the organism. These virtual functional models would realistically simulate the body's physiological reaction to injury, manipulation or disease. Private companies have been taking the lead in this aspect of virtual patient development. Most of these simulations are mannequin-based with substantial integrated interactive computer components. One such company is Entelos (Foster City, California) who describe their system development as follows: "After modeling human health, we introduce a disease state parametrically, based on disease data, creating virtual patients by changing variables within the system. In simple terms, we "give" the healthy human a disease, creating a virtual patient. We can create many virtual patients that represent known and hypothesized causes for the disease and, using biosimulation experiments, test therapies to understand the patient's likely response to treatment" (Entolos, 2005).

One of the most advanced efforts currently underway is the Virtual Soldier Program initiated in 2003 with supported of the Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO). The goal of the initial phase of this project is to build a virtual torso with morphological details extending from the gross anatomical to a cellular level. Drawing on the depth and breadth of current research and clinical data, the project is an attempt to incorporate a range of physiological components into the virtual computed model. The end point for this initial project is to demonstrate that a detailed computer-based simulation can be built that can accurately predict and display in real time, the complete range of morphological as well as physiological changes that occur immediately following a bullet wound to the chest and heart of a virtual soldier.

Just as the engineering industry has learned that computer aided design (CAD) and finite element (FE) testing of virtual models provide significant advantage, so the medical community will find major opportunities in virtual modeling of the structural and functional components status of

their patients. Detailed volumetric images, objective quantitative measurements, and statistical analysis of patient populations will support normative database development to serve as a yardstick for better and earlier diagnoses of a wide range of pathologies. Patient-specific virtual anatomical modeling will provide an opportunity for surgical procedures to be tested or practiced on the virtual patient prior to the actual surgery. The medical imaging and computer technologies have advanced to a level that virtual patient modeling can now be a reality. The virtual patient is about to become a reality that will play an ever increasing role in the practice of medicine of the 21st century.

References

1. Acherman, M.J., *The Visible Human Project*, Proceedings of the IEEE 86(3), 1998.
2. Ackerman, M.J., *The Visible Human Project: a resource for education*. Acad Med 74(6):667-670, 1999.
3. Hilbelink, D.R., *Three-dimensional Cartesian coordinate system for the human body*, Clinical Anatomy 18(8):627, 2005

Websites

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

Virtual Soldier Project: <http://www.virtualsoldier.net/>

Entelos: Quote Retrieved Dec 14, 2005 (<http://www.entelos.com/science/virtualpatients.html>)