Review

From Virtual Dissection to 3-D Surgery Simulation. The Use of a Computerized Body-Size Table

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Abstract

The aim of this article was to describe and explain our experience with Anatomage table in the teaching of anatomy and some easy surgical techniques. Anatomage combines stereoscopic images of the whole body with software in order to build a 3-dimensional (3-D) reconstruction of the different human body parts. These images were taken from two cadavers, male and female, who were frozen and cut into sections to allow for virtual dissection and reconstruction of the human body. Users can visualize anatomy exactly as they would on a fresh cadaver. The table allows for exploration and learning of human anatomy beyond the experience with a cadaver. It is possible to cut away from the body surface to the inner body using a scalpel, as well as to watch images of 3-D sections in the three spatial planes.

We described the importance of dissection in practical anatomy teaching, the problems that arise when using formaldehyde to embalm the bodies and the large number of body donations needed. Thus, many authors have proposed different solutions, such as anatomical videos and software with reconstructions of the human body or images of cross-sectional anatomy. But these techniques present limitations when trying to offer a real view of the human body internal structures.

Conclusion: Anatomage allows for anatomy teaching and learning in an interactive way. Students can practice actively and take the images watched in a practical session with them in a storage device, in order to study and discuss them later in a lecture. Anatomage is also used for practical anatomy exams and surgical technique simulation with students. Despite being rather costly, it stimulates the learning of anatomy by being directly used by students in various ways. Besides, it provides a large number of real medical cases, giving the opportunity to see the differences with normal anatomy and making the table highly versatile.

Key Words: Surgical Anatomy; Dissection; Anatomy Education; Anatomage

Introduction

Traditionally, anatomy teaching and learning were focused on dissection, which can be directly performed by students or guided by professors [1]. This is an important subject in medical schools' curriculum and it is considered essential by many authors, such as Turney [2]. However, new and more interactive ways of teaching anatomy have gained importance to help students and professors learn and teach the human body structure [3]. Several of these techniques include advanced imaging and some of them use videos, like Acland’s Video Atlas of Human Anatomy [4], software for interactive online dissection, like Gross Anatomy Dissector by Suarez-Quian [5], or anatomical software, the most renowned being Zygote [6].

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One of the most important parts of future physicians’ curriculum is preparation for surgery and this must include the knowledge of anatomy. Surgical anatomy consists in the use of anatomy in reference to surgical diagnosis, dissection or treatment. It is the study of the structure and morphological characteristics of the tissues and organs of the body as they are related to surgery [7]. This is required to obtain optimal knowledge on a particular surgical field.

One of the most usual techniques to acquire these skills is dissection. Dissection is the exposure and description of internal body organs and structures [8]. To achieve this goal, a large number of bodies need to be donated and perfectly fixed.

To reduce these needs and make anatomy teaching and learning easier, other techniques have been developed. One of these techniques is cross-sectional human anatomy, which was used in the sixteenth century by Leonardo Da Vinci, who included cross sections in some of his anatomical drawings. This technique was implemented and widely developed during the nineteenth century by anatomists such as Pirogoff and Braune, who published an atlas with figures in the three spatial planes (sagittal, coronal and transverse) of frozen cadavers sectioned with a band saw [9]. It was the precursor of harmless techniques developed in the last decades that allow us to know about our inner organs and structures. These techniques are called Computed Tomography (CT) [10] and Magnetic Resonance Imaging (MRI) [11].

Recently, a computerized body-size table has been designed combining CT scan, X-Ray, ultrasound and MRI, stereoscopic images of the different human body parts with software in order to build a 3-dimensional (3-D) reconstruction of the whole body. It is ANATOMAGE [12], a computerized table developed by a 3-D medical technology company located in San José (California) in conjunction with Stanford University’s Clinical Anatomy Division. This technology allows for virtual dissection and reconstruction of the human body. By means of a fully interactive multitouch screen, one can dissect the body, moving through layers of tissue or use a virtual knife to cut away and see the structures inside [13].

There is one Anatomage table at the Defense University Center (Centro Universitario de la Defensa) in Madrid (Spain). This new technology allows professors to teach anatomy to students and also to practice and simulate some surgical and invasive techniques before they experience real surgery.

**Traditional Anatomy Teaching**

The most common way to teach anatomy in a practical way has been dissection, which is the exposure and description of internal body organs and structures. It consists in dismembering the body of a deceased human to study the anatomical structure and it is typically conducted in an anatomy lab [14]. Before beginning the dissection, it is necessary to prepare the cadaver, including anatomical embalming. This is a process in which the dead human body is treated with chemical products to reduce the presence and growth of microorganisms in order to inhibit the organic decomposition temporarily. During this process proteins coagulate, tissues are fixed, organs are bleached and hardened and blood coagulates and turns into a pinkish brown mass. The main priority is long-term preservation [15]. Anatomical embalmers use embalming fluids that contain formaldehyde, glutaraldehyde or phenol. The best product to embalm is formaldehyde, but it has the problem of toxicity. Duong et al. [16] reported some evidence of association of formaldehyde exposure with cancer and adverse reproductive and developmental effects (teratogenicity). One possible solution is the use of glyoxal, an organic compound which is the smallest dialdehyde that works as a protein and tissue fixer; however, it is less fixative and preservative than formaldehyde [15].

The dissection laboratory provides an environment in which the senses of touch and vision can be used to enhance the understanding of the human body. Students can truly see and feel structures that lie under the skin, e.g. nerves, veins and arteries [17]. Although the number of laboratory hours in gross anatomy courses has decreased in most medical schools, the dissection laboratory continues to be a learning environment in which students of anatomy gain a 3-dimensional perspective of the relationships among different parts of the internal human body. Another option is the prospection, where a “prepared” specimen is preserved in a solution and pre-dissected by an experienced anatomist. Students follow the guidance and indications of the anatomist and study the parts and structures that are contained in a specific region of the human body [2].

Nevertheless, there are some problems related to anatomical dissection. The dissection requires a large number of body donations and their perfect fixation. Sometimes this is expensive and time-consuming. Besides, some countries have limited human body dissection based on ethical, moral or religious reasons [18]. Furthermore, some chemicals used to preserve the bodies, such as formaldehyde, are hazardous and forbidden in the European Union, so it is compulsory to change to others like glyoxal.

**Solutions and Alternatives**

Anatomical models are used in all medical schools to teach human anatomy to students. Other options are to use anatomical videos like Acland’s Video Atlas of Human Anatomy [4], online guided dissection like Gross Anatomy Dissector [5], anatomical software like Zygote [6] or Visiblebody.com, which contains a 3-D atlas of anatomical models [19].

One important contribution to the advance of knowledge and understanding of the human body internal structure was cross-sectional anatomy. This is an old, classical technique that was broadly developed during the 19th century, through which bodies were sectioned using a band saw. The body was arbitrarily divided into sections. One of the most renowned atlases that shows this technique is **Color Atlas of Anatomy. A photographic study of the human body**, by Rohren, Yokochi and Lütjen-
Drecoll [20]. The specimens used to prepare this atlas belonged to several bodies that had been embalmed using routine anatomical procedures and then thoroughly frozen. Sections are usually seen from below, looking towards the head (as radiologists do). Other important authors like Kim, E.E. et al [21] and Moeller and Reif [22] designed atlases based on cross-sectional anatomy. They used high-quality photographs to detail side-to-side anatomical cross sections and their corresponding CT and MRI images to clarify their location and structure. Reference drawings and their corresponding scanning planes accompany the images to help the user recognize the relationship between anatomy and imaging. This was an important step to the next advance, the 3-dimensional reconstruction of the human body internal structures.

**A Computerized Body-Size Table: ANATOMAGE**

Anatomage table is a technologically advanced anatomy visualization system for anatomy education and it is being adopted by many of the world’s leading medical schools and institutions [13]. Anatomage combines stereoscopic images of the whole body with software in order to build a 3-D reconstruction of the different human body parts (taken initially from two cadavers: male and female) that allows for virtual dissection and reconstruction. This computerized body-size table features a 7 by 2.5-foot screen and combines the technology of CT scan, X-Ray, ultrasound and MRI to reconstruct the human body [12]. Anatomage table is a fully segmented real human 3-D anatomy system. Users can visualize anatomy exactly as they would on a fresh cadaver. Individual structures are reconstructed in accurate 3D, resulting in a very high level of real, accurate anatomy, dissectible in 3D. The table allows for exploration and learning of human anatomy beyond what a cadaver could offer [13]. The use of virtual dissection technology seems to have a promising role in future educational training although more research is needed to better understand the efficacy of using this technology in the classroom. In this regard, Custer and Michael concluded that students appreciate learning with this technology and believe that it is a beneficial and effective tool in preparing them to enter a health care profession [23].

Anatomage currently offers four gross anatomy cases, more than 20 high-resolution regional anatomy cases and more than 1,000 pathological examples. Thousands of structures are meticulously segmented from photographic images to deliver the most accurate real 3-D anatomy. Individual vascular structures are also carefully traced [13].

Anatomage table-based education has proven to be effective. An increasing number of publications show improved test scores, more efficient classroom and lab sessions, and student acceptance. The table allows students to interact with young and well-preserved digital cadavers instead of aged and degenerated bodies. Students are also exposed to different anatomical variations and a large number of pathological variations. The accurate details and rich content draw students’ interest and attention, leading to more effective educational outcomes [13]. The incorporation of cadaver CT scans and life-size virtual dissection tables significantly improved the performance of medical students in general gross anatomy. Medical imaging and virtual dissection should therefore be considered to be part of the standard curriculum of gross anatomy [24].

Anatomage presents some noteworthy advantages compared with the use of cadavers. Embalming products or a special place for the anatomical table are not necessary. There are no restrictions and permits are not required to use it. The number of cases is almost unlimited and recurring costs are minimal, since it is not necessary to replace the cadavers every year. The anatomical accuracy in the reconstruction of the human body is very high, since it is based on real human bodies. It is also possible to cut and make sections of the body in any direction [25]. Despite Anatomage being rather costly, it can be used frequently and for a long period of time. Typically, its most usual application is dissection replacement. With a fully interactive, multitouch screen, it is possible to dissect the body, moving through layers of tissues or using a virtual knife to cut away and see the structures inside. Different types of visualizations can be used to look into the body, such as opaque hard tissue or as an X-Ray. Since the data preserves the real patient’s color and shape, the table turns to be more effective than embalmed cadavers [26,27].

Another feature of Anatomage table is the Digital Anatomy Library, which offers over six hundred clinical cases and includes data from vertebrate anatomy and embryology (version 4.0). Users can access the original scan data, the resulting 3-D image and medical case notes. This allows for many options, such as studying pathological examples, making comparative analysis, studying physicians’ own cases and sharing files, cases, and lectures with students and practitioners using storage devices [28].

Another option when using Anatomage is surgery simulation. Many of the patient scans included in the Digital Anatomy Library display medical devices. Instructors can demonstrate to students the location and function of stents, clamps, implants, and grafts. The 3-D patient scans can be cut and rotated in any direction to show medical devices in a new and intuitive way [28,29,30]. It is possible to create incisions and cuts to remove and uncover different layers of organic tissues to move deep inside step by step to know which structures it is necessary to look for. It is also possible to get guidance from the table. It can show the names of the structures seen in every plane, so that students learn what they need to do.

For example, it is possible to simulate an appendicitis surgery.

**Figure – 1:** First incision removing the skin.

**Figure – 2:** Second incision uncovering the muscular plane.

**Figure – 3:** Third cutting level uncovering the greater omentum.

**Figure – 4:** Fourth cutting level reaching the appendix.
Anatomage table also offers the option to combine scanning planes to get a better understanding of the location and relationships of the different human body inner structures. It is possible to combine the view at one level with the view of structures in the three spatial planes (sagittal and parasagittal, coronal and transverse), and to move up and down to check the structures at different levels of cross section. This allows the user to watch a complete and perfect 3-D view of the size, position and relationships of organs, vessels, nerves, muscles and spaces inside our body [28,30].

Figure – 5: Liver sections in the three spatial planes.

Figure – 6: Trunk and limb sections in the three spatial planes.

Figure 1: First incision removing the skin.

Figure 2: Second incision uncovering the muscular plane.

Figure 3: Third cutting level uncovering the greater omentum.

Figure 4: Fourth cutting level reaching the appendix.

Figure 5: Liver sections in the three spatial planes.
Anatomage and Surgical Planning. We have not used this feature yet, but it is possible to use the table as a simulation center with 3-D images. It converts multiple cross sections of traditional CT and MRI into a 3-D model which physicians and surgeons can manipulate to better understand the individual patient’s anatomy and the location of tumors in relation to nerves and blood vessels. Aase’s medical team was able to identify potential complications and develop a plan to ensure the best outcome. The patient underwent surgery successfully in shorter time than originally thought and without surprises [31].

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