Teaching and learning anatomy

Pedagogical methods, history, the present and tendencies

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Abstract

Human anatomy is a basic science which allows healthcare professionals (in training and graduated) to acquire a detailed and global understanding of what it means to study the human body. It provides a foundation in the technical language required for other basic, clinical and surgical sciences. The manner of teaching and learning anatomy has changed over time, and several pedagogical models exist which may be confused with didactic ones. The purpose is to observe educational aspects and reflect on the pedagogical models, resources and didactics used for teaching/learning human anatomy (history, the present and tendencies), recovering the value of anatomical knowledge in the training of doctors and other healthcare professionals. Current tools and new tendencies in anatomy informatics may complement, enliven and improve (but not replace) the basic pedagogical models of regional, system and clinical descriptive anatomy. **(Acta Med Colomb 2020; 45. DOI: https://doi.org/10.36104/amc.2020.1898).**

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Introduction

Perhaps the majority of this article's readers are healthcare professionals (in training and/or in practice), to whom the words "anatomy", "anatomy course" and/or "morphology classes" bring to mind a host of memories, anywhere from pleasant memories, including gratitude and nostalgia, to memories of animosity, frustration and despair. In any case, one thing is clear: anatomy classes plus the rest of the "basic" courses in medicine were a necessary evil for some, and a passion and way of life for others. However, they were, are and will be part of our medical training and that of other healthcare professionals, and they are an essential resource for several colleagues who view anatomy as the main support of their clinical practice or medical-surgical specialization, and/or an almost unlimited source of advances in terms of diagnostic imaging, surgical procedures, and rehabilitation and bodily restoration processes, among others.

The most basic definition of anatomy (health descriptors) is "a branch of biology dealing with the structure of organisms" (1) or a science which studies the structure of the body (2). But its definition and scope go beyond this. Anatomy is a basic science which allows healthcare professionals in training (undergraduate and graduate students), as well as those who have already graduated, to acquire a more detailed and comprehensive understanding of what it means to study the human body (3), in order to then contextualize it in the dynamic conditions of health, illness and disability. Human anatomy courses provide the initial foundation for the technical and anatomical language required for pharmacology, pathology, physiology, patient assessment, and surgical and therapeutic basics, along with those of each of the medical-surgical specialties and internal medicine. Anatomy is not considered to be the oldest basic science for no reason (4), and it was defined by Hippocrates (460-377 B.C.) in terms of the nature of the body as the beginning of medical science (4). Anatomy is, thus, the oldest basic science, the historic and traditional foundation of medical training, thanks to which the initial scientific approach to disease occurred (5).

The systematic and organized study of the structural make-up of the human body, an overall view of organic systems, vascular and nervous relationships, organization of the skeletal system, recognition of the textures of the body's tissues and organs, shapes and sizes of the viscera, and position and three-dimensional planes of the organism, are a few of the topics and teaching goals of human anatomy. Modern anatomy covers divisions and sub-disciplines such as systematic (or descriptive) anatomy, regional (topographic) anatomy, microscopic (histological) anatomy, developmental anatomy, functional anatomy, surface anatomy, endoscopic anatomy, neuroanatomy, clinical anatomy, surgical anatomy, applied anatomy, radiological anatomy, comparative anatomy, forensic anatomy, anthropological anatomy and artistic anatomy (3). This explains, to a certain

degree, why anatomy courses have extensive content and broad applicability, theory and practice.

Today, the way in which medical and other health sciences students study and learn anatomy needs to be analyzed and understood within a broader context of the teacher/student pair. It is increasingly evident in the basic sciences' learning processes, including that of anatomy, that the various courses tend towards greater integration, an orientation towards systems, the fostering of self-taught and significant learning (6), integration of new technologies and data cleansing. At the same time, anatomy content and information has increased, without necessarily having increased the time available for it within the universities' programs or anatomy courses (6). This situation leads to debates in the university pedagogical and administrative areas regarding how to conduct anatomy courses in the medical and health sciences schools and faculties, which pedagogical model to use, and what level of requirements to establish. The necessity of the basic sciences in modern medical training has even been questioned, at times without much justification, or human anatomy teaching models have been solely based on digital/virtual tools, and it has even been proposed that medical anatomy courses may be offered between semesters. It is important not to minimize the specific teaching approach needed to teach human anatomy, and not to lessen the students' (medical and other health sciences personnel in training) educational experience.

The way of teaching and learning anatomy has evolved over time, wherein various teaching models have existed, exist and will exist: the classical and regional model, systemic anatomy, and clinical anatomy. Today, the validity of the classical model for teaching anatomy is questioned, sometimes due to the obtuse concept that it is old and obsolete, but these ideas may be based on a poor interpretation and on confusing pedagogical and didactic resources (which are increasingly virtual, digital and dynamic) with pedagogical models in the effort to transmit and develop learning in the student. Anatomy, together with other basic undergraduate courses in medicine and other health sciences, provides the concepts for correlating and ordering functions, and identifying and separating physiological findings from pathological findings, tying in directly to the clinical disciplines (3, 7) and simply establishing the basis for clinical practice.

The purpose of this article is to consider educational aspects and reflect on the pedagogical models, resources and teaching tools used in teaching and learning human anatomy (history, present and trends), extracting the value of anatomical knowledge in medical and other health sciences training.

Historical context: the beginnings of anatomy and the classic teaching model

Allegedly, the first anatomical dissections of human beings were performed by Herophilus of Chalcedon (335-280 B.C.) and Erasistratus of Ceos (300-250 B.C.) (8), who also used vivisection, or experimentation on live animals (9). Herophilus first identified and described the optic nerves and retina, and differentiated nerves from tendons, showing that the nerves start in the brain and spinal cord and go to the muscles. Erasistratus, as Herophilus's student and helper, observed that the brain's ridges (convolutions and gyri) were more pronounced in humans than in animals, and postulated that fourth ventricle (rhombencephalic ventricle) injuries caused sudden death (9). It should be borne in mind that the history of medicine (which includes anatomy and the first dissection) incorporates anatomical records from places other than ancient Greece, such as Egypt (the Ebers papyrus and Smith papyrus), India (Ayurveda), Rome and the American aborigines (3).

Later, in the ancient Greek city of Pergamum, Claudius Galen (131-201 A.D.) used animal dissection methods (as human cadaver dissection was forbidden at the time) to develop a wide variety of anatomical descriptions including that of the dura mater, pia mater, corpus callosum, cerebral ventricles, and pineal and pituitary glands, as well as the identification of 11 of the 12 cranial nerves (others say seven of the 12) (9). Although he assumed that animal and human anatomy were the same, he offered functional descriptions of the structures, such as that muscles are controlled by the spinal cord, the difference between veins and arteries (where blood, not air, circulates), that the brain is responsible for controlling the voice, and the production of urine as a function of the kidney (5, 10). In addition, Galen detected that a spinal cord injury between the first and second cervical vertebrae caused instant death, and that if the section was between the third and fourth cervical vertebrae it caused respiratory paralysis (9). From the most noble and modest beginnings of anatomy, associations were made between the structure and function (functional anatomy) and between species (comparative anatomy), and basic explanations were given of some diseases (pathological anatomy).

Andries van Wessel, known by the Latinized form of his name, Andreas Vesalius (1514-1564), revolutionized medical teaching when he was only 29 years old with his book "*De Humani Corporis Fabrica*" (a 663-page book with over 300 anatomic and artistic illustrations) (11). Considered to be the father of modern anatomy, he corrected some of his predecessor Galen's errors (anatomical inaccuracies of the sternum, liver and origin of blood vessels due to Galen's emphasis on the comparative anatomy model). Although Vesalius was a quintessential anatomist, focused on structural descriptions, he also contributed a few pathological references such as aneurysms and tumors (5, 11).

Anatomy, a mixture of science and art, initially satisfied the natural curiosity regarding knowledge of the human body (3) and what we are as human beings.

As pictured in Rembrandt's masterpiece titled "The Anatomy Lesson of Dr. Nicolaes Tulp" (1632), in which Dr. Tulp gives a class on the forearm to a group of surgeons (and one or two "interlopers" who paid to enter the "anatomy theater"), the classic model is based on the teacher-student pair,

cadaver dissection by planes, description of structures, and macroscopic relationships by regions. The greatest topical development in anatomy (descriptive and topographical) is reported to have been in the nineteenth and early twentieth centuries, leading to the founding of the Anatomical Society of Paris (1803) by Dr. Dupuytren and Dr. Laennec, in addition to the first attempt to unify anatomical nomenclature in Basel (1895) (3).

Description of the basic models for teaching and learning human anatomy

The most common methods and models for studying and learning human anatomy are regional anatomy, systemic anatomy and clinical anatomy.

Regional or topographic anatomy is based on the organization of the human body by parts and segments (head, neck, trunk and extremities), areas and regions, identifying the organization of the body by layers. It uses surface anatomy to identify the palpable structures (the basis of physical exploration). Usually, anatomy courses at medical or health sciences schools with an available dissection laboratory use this model (12).

Anatomy by systems (systemic anatomy) is based on the study of each of the organism´s systems which explain complex and integrated functions. This model provides the basis for clinical, medical-surgical and other health sciences specializations. In general, systemic anatomy studies the integumentary system (dermatology and aesthetic medicine), skeletal (osteology), joint (arthrology) and muscular (myology) systems (three basic systems for orthopedics, traumatology, physiatry and physical therapy), nervous system (neurology, and, in turn, includes the sense organs; the object of study of clinical neurology, neurosurgery, psychiatry, psychology, otorhinolaryngology, ophthalmology, speech therapy and optometry), circulatory system (angiology), lymphatic system (fundamental for internal medicine and oncology), digestive system (gastroenterology), respiratory system (pulmonology, respiratory therapy and speech therapy), urinary system (urology), reproductive system (gynecology, andrology and sexology), and the endocrine system (endocrinology) (12).

Meanwhile, clinical or applied anatomy uses relationships between structures (be they regional or systemic) and function to explain and/or resolve clinical practice cases (12). Thus, the clinical anatomy model (also known as medical-surgical anatomy) relates human anatomy to diagnosis, treatment and surgical interventions (3). This is an integrative model and fosters the anatomical-clinical and pathophysiological analysis needed to make a case for clinical practice. However, the anatomical foundations provided by regional and systemic anatomy are necessary for applying and discovering the exciting model of clinical anatomy. Anatomy's pedagogical models are complementary, not exclusive, and they may be potentiated by various resources and didactic tools.

The didactic tools for operationalizing the previous models' teaching (especially the regional and systemic models) include practical learning or dissection. In 1770, Dr. William Hunter stated that dissection in and of itself teaches where a live subject may be cut or inspected with freedom and promptness (12). Dr. Moore mentioned the importance of observation and palpation, in addition to movement and dissection of the various regions of the body, and he pointed out that dissection is a perfectly established research method that constitutes a very stimulating learning pathway, if the student understands the clinical significance of the structures being dissected (4). Thus, dissection is the most classic and historical teaching tool for enlivening anatomy's basic teaching and learning models, so why is there an effort to dismiss it or remove it from some medical and health sciences schools? The authors of this article propose another type of question: why not, rather, complement it and update it with new resources and teaching tools based on imaging, informatics, and 3D and immersive models (like mixed reality)? (13).

The complementing of cadaver dissection to combine teaching tools and enliven the learning of human anatomy began with the diversification of diagnostic imaging (in the 70s-80s), giving rise to radiographic anatomy. This discipline makes the regional study of deep structures and systems integration possible, supplying information which is not obtained by cadaver study alone, such as anatomical variations, the effects of muscle tone, bodily fluids, pressures and structural detail of the organs (12). But just as with clinical anatomy, a good radiological anatomy requires anatomical foundations derived from the basic models: regional and systemic anatomy. Once again, the complement between pedagogical models and operationalization of the teaching, using various methods and teaching tools, is proposed.

Models, methods and tools in use at this time

Currently, the teaching and study of human anatomy in both medical and other health sciences schools is going through a critical and transitional time. Over the last several years, with the introduction of the digital era into our reality, the perception of how the morphology of the human body can be taught, learned and studied has changed, in large part spurred by the generation gap between teachers and students, as well as by administrative tensions between cost-benefit, academic quality-resource optimization and program profitability. This has led several medical schools to revamp their curriculum, cut learning hours, and even reduce the details and content of their anatomy course, as well as emphasize the use of the clinical anatomy model focused on the student as a future healthcare professional rather than an anatomist (14-17). The revamping of anatomy course curricula explains, in part, why the anatomy pedagogy and teaching models are not uniform across institutions (18) and programs.

Modern literature reports concern regarding the anatomical knowledge of the physicians in training, and the detrimental effect this may have on their professional and clinical practice (19), and even how a poor training in anatomy can affect patient safety throughout the multiple healthcare processes (3).

The critical review of the literature carried out by Estai and Bunt in 2016 mentions dissection, prosection, plastination, anatomical informatics, imaging, and living anatomy plus other teaching models based on readings, integrated curricula and systems-based curricula as modern tools and methods for teaching anatomy (16).

Dissection is a method characterized by individual or small group experiences in which anatomy is actively explored in bodies (cadavers), sectioning in each of the body planes in order to divide and find the anatomical structures being studied. This didactic tool, together with teaching based on lectures and master classes, has been the quintessential teaching tool employed for more than 400 years in teaching anatomy (20) using the regional and systemic model. Some critics consider it to be a costly method, requiring a large investment in time, and outdated (21). In some medical schools, it has been replaced with methods such as prosection combined with other teaching modalities (22).

Prosection is the method through which students learn from an already dissected cadaver, providing an approach to the real anatomical structures without the need for endless hours of dissection (23). Usually, these exhibits are found in anatomy museums as well as in human anatomy/morphology labs.

Plastination is a preservation technique using chemical materials which are injected or introduced into dissected cadaver structures and even whole bodies. The method was created by Gunther von Hagens at Heidelberg University's institute of anatomy (1977) (16). This technique limits the number of dissections, is odorless, and the anatomical preparations are easy to preserve without chemical preservatives (such as those required for dissection and prosection) (24).

Living anatomy consists of the anatomical study of another living being without the need for dissection. For example, carrying out a physical exam of their own bodies, their peers or simulated patients to identify forearm tendons or palpable bony parts on the extremities. It includes painting or drawing anatomical structures on the skin to understand the underlying morphology, and supplies useful relationships for spatial location (25, 26). It also includes specially designed clothing so that, for example, the students can better understand the concept of dermatomes (14).

The technological advances of the twenty-first century have led to the birth of anatomical informatics, which creates 2D or 3D models and reconstructions of anatomical structures (of healthy individuals and patients), systems, and the whole body. This method has popularized the term "virtual or digital cadavers/bodies", which can be shown and manipulated on computers, tablets, digital screens and smartphones, or through online virtual education platforms as e-learning modules, flipped classrooms, simulation and/or social networks (16, 25). Today, part of the theory and use of 2D/3D anatomical models is performed remotely, thereby complementing master classes and on-site laboratory practice. This line of tools and computer developments for anatomy currently leads to trends such as virtual reality, augmented reality and mixed reality (13, 16), haptic technology, the projection of images onto students and 3D printing (14), and virtual dissection tables.

In some universities, the combination of teaching methods using cadavers, prosection, and plastination plus plastic replicas, together with master classes, are the foundation for teaching (25).

The comparison of anatomy models, methods and tools has created a research field. Cadaver-based education and learning has survived as the main teaching tool for hundreds of years, but in light of the new modalities mentioned, there are differing opinions on whether complete cadaver dissection continues to be appropriate for modern university training (16). There are studies supporting the usefulness and use of cadavers in the decade from 2010-2020, in which several universities in the United States, Australia and New Zealand, who had abandoned cadaver-based anatomy teaching, resumed it a few years later (14).

A systematic review of 21 studies comparing the use of digital methods or anatomical informatics with traditional methods concludes that three-dimensional digital displays seem to be a more effective method for acquiring anatomical knowledge, and create greater motivation and interest in the students (27).

A descriptive study of a sample of 74 students at the Universidad de Las Palmas de Gran Canaria (Spain) (28) sought the opinion of students who had been raised with information and communication technologies regarding the methods used at their study center in the human anatomy teaching-learning process. They found that, in general, the best rated methods were clinical case studies and the identification of human structures in the dissection laboratories, with the main advantage being the three-dimensional identification of anatomical structures and consequent consolidation of anatomical knowledge (29).

Controversially, a meta-analysis published in 2018 (27 studies with more than 7,500 participants between 1965 and 2015), which compared dissection with other methods (prosection, digital media, anatomical or hybrid models), concludes that there are no differences in terms of short-term learning gains (the students' performance on knowledge exams was similar regardless of whether they were exposed to dissection or another strategy). In addition, it is unclear if the concept of long-term memory creation is consolidated equally or better using dissection versus other methods (30).

In turn, several comparative studies (30, 31) have not found one model or teaching method to be better than another. It seems that the best way of teaching modern

anatomy is to combine resources and didactic tools which complement the pedagogical model(s) employed in anatomy. Students appear to learn more effectively when multimodal approaches are integrated (16).

Medical schools in Latin America continue to combine the traditional with the modern, having a multimodal strategy: to combine technology with the use of anatomical exhibits. One advantage of cadaveric anatomical exhibits is being able to observe the anatomical varieties which show the real make-up of the human body, considered to be a high-impact moral, reflective, emotional and psychological activity (32). Therefore, for some medical and health sciences schools, it is still essential to have morphology laboratories for teaching anatomy (17). In addition, cadaveric material facilitates and provides the student with an initial approach to humanistic values, respect and professional ethics (33).

Likewise, several comparative studies conclude that a mix (between the traditional and the technological) has better results than using any of them separately (34).

New trends in human anatomy teaching and learning

In the midst of an increasingly innovative society and culture, in which communication and new technologies lead various teaching and instruction processes today, it is hard to imagine that the basic health sciences, including anatomy, would not have progressed and migrated towards them. However, it is also true that this has been a slow but steady process, not just in adoption but also in application, for both teachers and students (35).

The use of real anatomical parts (cadavers) is without a doubt the gold standard and fundamental pillar for teaching anatomy (regional, systemic, surgical, developmental, neuroanatomy, forensic and anthropological), but some countries' laws (including Colombia's), make it difficult to obtain them, driving various strategies to try to supply the need (36) through 3D systems and anatomical models similar to anatomical dissections, in which the anatomical characteristics and relationships may be viewed in detail (37).

Therefore, when we speak of new trends in teaching human anatomy, we are referring to technologies such as virtual reality (immersive) and augmented reality (non-immersive). These are pedagogical tools and strategies that can break paradigms, which were only available to great anatomists because they were considered to be authorities on the subject of descriptive anatomy due to their great findings in their experience of body dissection. One objective of these technologies (which are resources and didactic tools) is for people to be able to learn concepts that may be complex from significant experiences, replacing passive classes (38).

Augmented reality is a technology that combines digital information and real information from the environment (non-immersive) through a camera, tablet or mobile phone. Virtual reality transports users to a completely artificial environment (immersive), blocking the information from the physical environment (38)

Using these technologies, the silhouette of the organs can be modeled (without the internal content), organs can be modeled by layers (where there is internal content and average anatomical relationships) (13), or 2D/3D images from multiple magnetic resonance (MR) sections of the whole body, regions or particular organs can be used (37).

Interaction is allowed through a pointer, voice commands or gesture recognition. There is also tactile (haptic) feedback which is possible through thermal, vibration or mechanical stimulation devices included in the hardware. Anywhere from simple virtual and/or augmented reality (even mixed reality) devices to large exoskeleton devices which attach to the user and provide tactile feedback can be found.

Virtual reality provides access to surgical anatomy settings through various approaches and a prediction of realistic results, although it is limited by loss of visual freedom and of manipulation due to tactile feedback (39). Three dimensional interactive tables (or 3D dissection tables) are also considered to be technologies with great educational potential which provide the student with the opportunity of exploring life-size anatomy.

Another trend is 3D printing. Three dimensional printouts are another, complementary alternative for teaching regional and systemic anatomy. They consist of creating three dimensional structures, using controlled additive layer manufacturing (manufacturing by superimposing layers of material, generally plastic) from virtual plans and models of anatomical structures (which may be scanned by MR or tomography). Once the virtual models are obtained, various tissues can be differentiated (arteries, veins, and nerve, bone and muscle tissue), and the printing process materializes them, recreating different textures and colors in order to obtain models that are more similar to the real organs (40).

Advances in 3D printing have led to developments such as human organ printing using collagen to design heart (41) or biocompatible (42) components (bioprinting), abandoning the use of silicone models.

Controlled, randomized studies have been carried out comparing the effectiveness of teaching on the ventricular system of the brain using 3D printed models versus 3D images projected on digital screens. One of these studies reported that the 3D printouts substantially improved the effectiveness of the teaching on the ventricular system and increased the students' interest and enthusiasm, improving enjoyment and attitude. The authors concluded that this could stimulate the students' curiosity and lead to better effectiveness of the teaching (43).

A systematic review compared nine articles evaluating the learning process, understanding and enjoyment of students using 3D versus 2D models. The results of the different articles showed that, in general, students who used 3D printed models finished the tests faster, and improved their performance and understanding of the principles studied (44).

As a basic rule, the use of new technologies in teaching human anatomy should allow a better study and understanding of the various structures of the human body, or at least be comparable to the teaching provided in the previously used models. These new technologies are promising in the field of education and offer the advantage of greater accessibility and easy acquisition for educational institutions, especially those which have opted to migrate away from or not use cadaver dissections (45). However, it should be clarified that these technologies are didactic tools, not pedagogical models.

The excellent and almost limitless informatic aids currently available collaborate and allow greater conceptualization between structure and function, but in no way do they replace or substitute for learning models and laboratory training (3).

Final reflections

A noble purpose of anatomy courses in medical schools and other health sciences programs is to support the student in acquiring the basic structural and functional concepts of the human body, and in the middle-term (as he/she continues to progress through the program, studying other basic and clinical sciences) and long-term (in his/her life and professional relearning), to support his/her clinical reasoning, which is needed in the process of regional diagnosis in primary care, interpretation of diagnostic images, performance of surgical procedures, and prescription of treatment and functional rehabilitation processes. A section of the statutes of Florence University (1388) stated that that no one could be a good doctor and be adequately trained unless he were familiar with the anatomy of the human body (46).

The pedagogical models for teaching and learning human anatomy have been, are and will be a source of innovation and development of tools and didactic resources. Thus, the current tools and described trends can complement and invigorate the pedagogical models, whose foundation consists of descriptive regional, systemic and clinical anatomy.

Traditional classroom education should be complemented, but not replaced, by distance learning strategies, virtual platform content and digital collaboration environments. Likewise, the new methods of anatomical informatics complement, invigorate and improve the traditional model (regional and systemic) and didactic strategies based on dissection, prosection or plastination.

The models for teaching and learning anatomy endure and continue: the big changes lie in the tools and pedagogical didactic strategies, where the ultimate challenge is to integrate them into the teaching process.

The big question remains whether virtuality and its various anatomical informatics tools, by themselves, can completely replace anatomy laboratories and the teaching of cadaver dissection, or be tools for integrating and invigorating various pedagogical models, including the traditional model and dissection.

Another point for reflection is the usability or real applicability of 3D models derived from anatomical informatics in anatomy courses, since we cannot fall into the fallacy of flashy models and devices which are very well-designed, visually, but which offer minimal anatomical detail in accordance with regional anatomy, systemic anatomy and clinical anatomy models.

Conceivably, a successful human anatomy teaching and learning process is based on the combination of models, the integration of tools and pedagogical activities, and the inclusion of technological advances, with the aim of improving, not destroying, the classic cadaver-based model. The question is how to improve the educational experience of the student (healthcare personnel in training), create knowledge and use various didactic strategies for human anatomy.

Finally, it is not about good and bad models, or about destroying the classical model and imposing anatomical informatics technology and virtual education processes. It is not about extremes; likewise, an unexpected lesson of the COVID-19 contingency is that virtuality requires classroom and human contact, contrary to the question in education as a whole prior to the 2020 pandemic, which was how to make education more virtual and less face-to-face.

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