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TEACHING ANATOMY

Teaching medical anatomy: what is the role of imaging today?

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Abstract

Purpose Medical anatomy instruction has been an important issue of debate for many years and imaging anatomy has become an increasingly important component in the field, the role of which has not yet been clearly defined. The aim of the paper was to assess the current deployment of medical imaging in the teaching of anatomy by means of a review of the literature.

Materials A systematic search was performed using the electronic database PubMed, ScienceDirect and various publisher databases, with combinations of the relevant MeSH terms. A manual research was added.

Results In most academic curricula, imaging anatomy has been integrated as a part of anatomical education, taught using a very wide variety of strategies. Considerable variation in the time allocation, content and delivery of medical imaging in teaching human anatomy was identified. Given this considerable variation, an objective assessment remains quite difficult.

Discussion In most publications, students' perceptions regarding anatomical courses including imaging anatomy were investigated by means of questionnaires and, regardless of the method of teaching, it was globally concluded that imaging anatomy enhanced the quality and efficiency of instruction in human anatomy. More objective evaluation based on an increase in students' performance on course examinations or on specific tests performed before and after teaching sessions showed positive results in numerous cases, while mixed results were also indicated by other studies.

Conclusion A relative standardization could be useful in improving the teaching of imaging anatomy, to facilitate its assessment and reinforce its effectiveness.

Keywords Medical imaging · Radiologic anatomy · Teaching · Learning · Undergraduate medicine education · Anatomy

Abbreviations

CT	Computed tomography
IA	Imaging anatomy
MRI	Magnetic resonance imaging
US	Ultrasonography

Introduction

For many years, medical anatomy education has generated intense debates throughout the world, arising from various considerations including: exponential expansion of medical knowledge [35], increasing numbers of medical students [55], the advent of medical curricular reforms in many medical schools or new national guidelines in different countries [23, 25, 41], the move to integrated clinically based curriculum [6, 13, 100], recurrent debates on cadaveric dissection [1, 50, 63], the need and opportunity of improvement [16], the hope of coping with modern practice and improved information technology [84].

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Besides the two traditional keystones of teaching anatomy, e.g., didactic lectures based on drawings [10, 48] and dissection, other modalities have arisen (interactive multimedia, surface and clinical anatomy, plastinated and plastic models, problem-based learning, virtual simulations, etc.). Among them, a great deal of potential for imaging anatomy has been highlighted by numerous authors [9, 22, 50, 54, 55, 66, 80, 84].

On the one hand, recent technical advances offer new tools to use medical imaging for teaching anatomy [26, 27]. On the other hand, improvements in information technology have increased the ways in which diagnostic images can be displayed, transferred and stored [54]. In addition, imaging anatomy (IA) presents several key advantages: IA is close to the practice of future physicians, is living anatomy, uses digital technologies and provides per se a great variety of learning resources.

However, the practical role of IA in medical anatomy curriculum has not yet been clearly defined anywhere. The aim of this paper was to assess the current deployment of medical imaging in the teaching/learning of anatomy in medical curriculum by means of a review of the literature.

Materials and methods

Search strategy

A systematic search was carried out using the electronic database PubMed, ScienceDirect and various publisher databases.

The search was performed to include publications up to April 2015 with various combinations of the following key words: "Education", "Undergraduate Medical Education", "Teaching", "Learning", "Anatomy", "Cross-Sectional Anatomy", "Radiology", "Medical Imaging", "Diagnostic Imaging", "X-Rays", "3-D Imaging", "Magnetic Resonance Imaging", "Ultrasound Imaging", "Ultrasonography", "Computed Tomography Scanner, X-Ray", "Four-Dimensional Computed Tomography", "4D Computed Tomography", "Multidetector Computed Tomography", "Internet", "Online systems" and "PACS (Radiology)".

The results of a manual search of pertinent articles obtained from the reference list of the selected publications were added to the electronic search, yielding further references.

Reports in the gray literature were not pursued.

Selection of studies

Articles were reviewed for relevance and carefully examined; references of pertinent papers were hand-traced in the limit of up to 100.

Results

Today, in most academic curricula, imaging anatomy has been integrated as a part of anatomical education, according to a very wide variety of strategies.

Teaching approaches using X-rays were first reported in the 1970s [36, 39, 81]. Surveys showed that IA was integrated in gross anatomy instruction in about 70 % of medical schools in North America in 1985 [2] and in 80 % of them in 2006, but for an average of only 5 % of the course time [22]. In the last 5 years, IA was included in the anatomy courses of 92 % of Canadian medical schools [34] and 100 % in Australia and New Zealand, however, without more details [11].

The most striking finding of these results is the considerable variation in the time allocation, content and delivery of IA, not only throughout the world, but also between individual institutions in only one country [11, 54, 55, 66].

To classify these results, instructional methods of imaging anatomy may be schematically divided into three main kinds: (1) those that involve in-person teacher presence (traditional lectures, group learning with an instructor, rotating laboratory instructors, etc.) (2) self-instruction activities (Web-based modules, computer-assisted programs, etc.) and (3) the specific case of dissection and medical imaging combined sessions, bearing in mind that these methods may often be intermingled [16, 24, 38, 79].

Imaging anatomy as an integrated part of anatomy courses with in-person lecturer presence

In the different studies, IA could be part of anatomy courses in traditional curricula, in system-based courses, or in integrated curricula.

Besides traditional lectures, various formats such as tutor-led small groups, workshops, tutorials, demonstrations, rotating laboratory instructors and small group discussion and/or instruction, have been reported.

Teachers might be either anatomists or radiologists. Academic staff, postgraduate tutors, near-peer teaching assistants, radiology residents and radiology registrars were regularly mentioned. Having a dedicated staff member with radiological expertise in the anatomy department was of great value, but not frequent. In several papers, the importance of arrangements between anatomy and radiology departments, which is most often a local matter, was pointed out. Lecture theaters and dissecting rooms were the venues most often used in teaching IA.

The number of hours of teaching, the way in which it was delivered, the global organization, the image technology and the mode of presentation varied considerably. Here are some examples.

In 1985, according to the survey carried out by Bassett and Squire, the most frequent format for teaching anatomy including IA was classroom lectures alone or a combination of classroom lectures and small group instruction [2].

As early as 1990, Erkonen et al. described the integration of a new module of imaging anatomy within an existing course of gross anatomy, with a special emphasis on cross-sectional anatomy [19]. After two lectures devoted to radiation protection and basic principles of computed tomography (CT) scans, magnetic resonance imaging (MRI), ultrasonography (US) and X-rays, the module included six radiography–anatomy correlation sessions. According to a long-term follow-up published 2 years later, this integration provided significant improvement in the students' ability to identify anatomic structures on diagnostic images [20].

Since 1996, a variety of short sessions of teaching human anatomy by means of US, most often along with traditional teaching methods, have been reported [7, 17, 28, 30, 33, 72, 83, 86, 92, 95], using different strategies. For example, in the demonstration of the 'living anatomy' of the abdomen, pelvis and neck for large classes reported by Stringer et al., scans were performed by an experienced sonographer using a young female model as the subject, with images projected on to a large lecture theater screen, while medical student interaction was encouraged by two clinical anatomists [83]. The comprehensive ultrasound education for first-year medical students presented by Rao et al. consisted of six organ system sessions that addressed the basics of ultrasound techniques and the anatomy of musculoskeletal, vascular, cardiac, abdominal and genitourinary ultrasound [72].

In a very different format reported by Worthington, imaging anatomy teaching was organized in 2 h classes for first- and second-year students, divided into seven to eight groups, rotating around stations at 8 min intervals [97].

In another different way, radiological anatomy lectures and laboratory exercises were introduced to the revised curriculum as follows: at the end of each unit, radiologists were invited to lecture on the basics of reading radiographs, CT scans and MRI of each region and light-box exercises were introduced for students to examine plain radiographs, CT and MRI studies [35].

Combining medical imaging and dissection

Plain radiographs, US, CT scans and MRI images have been directly included in cadaveric dissection sessions in several anatomical education courses. Besides, Web-based and/or computerized medical databases have also been created to indirectly enhance the dissection experience [24, 52, 53] (cf infra).

In the 1980s, plain radiographs were used in dissection rooms in several medical schools to generate student interest in both anatomy and radiology, make anatomy clinically relevant and supplement the laboratory manual by guiding the student [62]. In the report by McNiesh et al., plain radiographs of cadavers were performed prior to dissection for first-year medical students in the gross anatomy laboratory to provide the opportunity for radiographic–anatomical correlation [51]. The authors emphasized the students' enthusiasm and the improvement of student–faculty communication and teaching relationships. Pabst et al. reported presenting X-ray anatomy by a roentgenologist in dissection rooms, with three other supplements (living anatomy, presentation of patients by clinicians, films on clinical problems) in addition to lectures and a dissection course for first-year students. According to the authors, this method generated a high level in students' interest [61].

Portable US has been used in dissecting room sessions for medical students to correlate US images and anatomical structures of the upper and lower limbs [85]. After an initial US demonstration carried out on a volunteer, the students were given the opportunity to use the US and identify normal anatomical structures such as bones, muscles and blood vessels. The session was evaluated by means of questionnaires distributed to the students and eventually considered as useful by a majority of them.

The combination of cadaver dissection and CT images of the same body helps the student to compare direct observation with the appearance in imaging and provides a comprehensive perception of the internal 3D structure of the human body, as well as a better understanding of diagnostic radiology. The use of postmortem CT images during cadaver dissection has been reported, discussed and most often emphasized by several authors [5, 29, 57, 60, 67, 80]. The hypothesis that "the use of cadaveric CT scans in the anatomy laboratory is positively associated with performance in the gross anatomy course" was tested and verified by a study carried out with first-year students who had the choice to use or not use CT scan images during cadaveric dissection [42]. Conversely, it was showed later by the same author that there was no added advantage in having the CT scan of the actual dissected cadaver [43]. The use of a computer-based dissection manual including images from cross sections, radiographs and CT scans in the dissection room has been described by Reeves et al. [73]. In a "millennial" laboratory, Benninger et al. investigated the integration of full-body dissection anatomy and modern hospital technology, during a 12-week anatomy course [4]. Examination scores proved to be a positive outcome, while feedback from students was overwhelmingly positive. According to the author, imaging should not be a small adjunct to understanding full-body dissection, but rather full-body dissection aids in the understanding of radiology mediums.

Technical concerns regarding postmortem images have been discussed with some discrepancies [3, 8, 78]. Chew et al. described important CT image quality degradation due to the postmortem state and artifacts of preservation [8]. In the study carried out by Schramek et al., four different imaging techniques (plain radiographs, US, CT scan and MRI) were performed on embalmed human body donors to analyze the quality of the images. The cadavers investigated were preserved with standard embalming techniques, using a solution containing ethanol (77 %), unbuffered formalin, glycerin and distilled water ($\sim$7 %, respectively) [78]. The quality of US and plain radiograph images was considered as poor, while images of CT scans and MRI were of good quality. In the study carried out by Benkhadra et al. [3] investigating ultrasound-guided punctures in cadavers embalmed according to Thiel's method compared with fresh cadavers, the results were considered as excellent for the former and such cadavers were recommended as realistic and lifelike models.

Virtual dissection, by means of interactive anatomy visualization workstations, opening any medical imaging data and providing 3D renderings, seems a very promising educational tool, but needs still further scientific evaluation.

Web-based resources and/or computer-assisted learning

Web-based resources and/or computer-assisted learning devoted to imaging anatomy have been integrated in anatomical courses, according to a wide variety of strategies.

These resources might be either part of the university's core anatomy curriculum [18, 44, 73, 91] or elective self-learning modules running in parallel with the anatomy curriculum [38, 68]. Of course, a great number of well-known and completely independent materials are widely available for extra-curricular non-taught knowledge [40, 93].

Some of these resources were combined with traditional lectures or both lectures and dissection [21, 35, 46, 47, 79], or were specifically designed to supplement, or be centered on, the laboratory dissections [18, 24, 52, 73].

They could encompass the whole anatomy course [68], or be devoted to the specific field of anatomy or to particular topics [14, 82].

They might include videotapes, CD-ROMs, online lectures, computer-assisted media, Web portals, Web-based laboratories and tutorials, presentations with graphics [24, 38, 59, 66, 91] or radiological digital teaching files [46, 47]. This kind of file has become increasingly easy to develop with the advent of picture archives and communication systems (PACS) and the Internet [77].

Some of these resources were specifically devoted to a specific image technology, for example CT scan images [49] or combined different image technologies, for example CT scan, MRI and US images [38]. Online radiology atlases with study guides have been created [68]. Sophisticated organization was also encountered, as was the case for the web site described by Granger et al. [24]. This site was organized by body region modules, the dissection videos for each region being the centerpiece of the program, with links to relevant images from the Visible Human Project, Netter Presenter plates, a radiological program including labeled radiographs, CT scans, MRIs and angiograms, and self-examinations [24].

Three-dimensional anatomical images

A three-dimensional approach of the anatomical regions and the complex spatial anatomical structures has evidently aroused a high interest for a long time and the effectiveness of three-dimensional visualization technologies in teaching anatomy has been evaluated by several studies [31, 98]. Today, thanks to advances in medical imaging and improvements in information technology, three-dimensional educational images may be very easily created from clinical images, as well as from human bodies donated to science, in addition to being well adapted to Web-based and/or computer-assisted formats. They replace various materials such as wax, bronze, ivory and papier-mâché, among others, which have been used for many centuries to create three-dimensional models for teaching anatomy.

Clinical images may be obtained in particular from high-resolution CT and MRI scans [32, 71, 87, 93, 94]. Regarding the human bodies donated to science, the Visible Human Projects, which were launched in the USA, have now been developed and/or have foreign mirrors in several countries and allow for providing three-dimensional reconstructions by means of CT scans and MR images [12, 71, 93, 96].

From a practical point of view, a variety of software and/or workstations are currently easily available [32, 71, 94, 99].

Numerous examples of three-dimensional educational computer models or programs that have been created from CT scans and/or MR images have been reported in the field of head and neck anatomy, for example regarding the larynx [32, 90], the temporal bone [70], the cranial nerves [99], as well as various regions of the human body, such as the vascular structures [65] or the gastrointestinal anatomy [89], among many others.

Beyond the teaching of anatomy for undergraduate students, it has also been pointed out that 3D computer-based models provide a means for realistic training in the interpretation of radiological and endoscopic images of the human body and may be useful for certain surgical procedures [71].

Discussion

The considerable variation regarding the global organization of IA in teaching anatomy, as well as its content and delivery, has been pointed out by previous studies carried out in the UK and Ireland [55], in Australian and New Zealand medical schools [11] and the PubMed search performed by Phillips et al. [66]. The question previously asked by Craig et al. regarding global anatomy teaching seems particularly relevant regarding the role of imaging anatomy: "Such variability in anatomy teaching and assessment raises an important question: is there also variable depth of understanding of anatomy between graduates of different medical courses?" [11].

According to our study, a very wide variety of answers have been given to three fundamental questions regarding teaching imaging anatomy: who, when, where?

In our experience, the greatest impact is observed when teachers are clinicians (illustrating the bases of the concept of clinical anatomy), the best time is the period of medical semeiology teaching (rather than the very beginning of the teaching of anatomy) and teaching at the bedside of the patient may be an interesting additional venue to those previously reported.

Another important question is that of the effectiveness of the role of IA in teaching anatomy. Given this considerable variation, an objective assessment remains quite difficult.

In a great number of articles, students' perceptions regarding anatomical courses including IA were investigated by means of questionnaires. In most cases, regardless of the method of imaging anatomy teaching (in-person teacher presence, IA–dissection combined sessions, Web-based and/or computer-assisted resources), it was globally concluded that IA enhanced the quality and efficiency of instruction in human anatomy [4, 7, 15, 24, 45, 49, 56–58, 61, 62, 72, 83, 91]. In most cases, IA was considered as "having generated a high level of students' interest in gross anatomy", or "improved their understanding of anatomy".

More objective evaluation based on an increase in students' performance on course examinations or on specific tests performed before and after teaching sessions showed positive results in numerous cases [4, 17, 19, 20, 38, 52, 68, 72, 75, 89].

Conversely, no increase in efficiency was reported in some papers. In the study reported by Sweetman et al. after a 2-h session on abdominal anatomy using ultrasonography in small groups, a short examination containing questions about ultrasound images and performance of a clinical skill (gastrointestinal tract examination) showed no appreciable impact on skills or understanding related to abdominal anatomy and examination [86]. Phillips et al. reported no difference in examination scores after additional direct and simultaneous correlation of radiologic and cadaveric structures, but underlined the help they provided in the students' understanding of anatomical concepts in comparison with other course components.

In a study that compared the efficacy of ultrasound imaging and cadaveric prosections for learning cardiac gross anatomy, Griksaitis et al. found no difference between these two cardiac anatomy teaching modalities [28]. A three-dimensional computer model was equivalent to standard two-dimensional images for the purpose of laryngeal anatomy teaching in the study performed by Tan et al. However, students preferred using the three-dimensional model [90].

Generally speaking, the effectiveness of computer-aided learning and Web-based resources still remains under debate [37, 64, 74, 88]. It has been pointed out that there is insufficient evidence to show that computer-aided learning has a true place for replacing traditional methods in teaching anatomy [88]. A study carried out by Rizzolo et al. showed no correlation between Web usage and examination performance in a human anatomy and development course [74]. According to the study of Murphy et al., self-directed learning was not favoured as a gross anatomy teaching format among medical students [58].

Regarding the effectiveness of multimedia resources in tertiary-level life science education, a meta-analysis carried out by Rolfe and Gray showed that, although it did not improve short-term learning gains, multimedia improved learning gains in 10 of the 16 sub-group comparisons made across all the studies of their work [76].

Finally, to create a fundamental curricular tool by which medical imaging education—both normal and pathological—may be taught and assessed in the future, a specific adaptation of the revised Bloom's taxonomy for Medical Imaging in Gross Anatomy by Phillips et al. [69] has been proposed.

Conclusions

Imaging anatomy is a living anatomy and, from a practical point of view, a great part of "useful anatomy" for numerous medical students in their future practice. A number of digital devices are particularly relevant to using IA, which is generally welcomed by the students. However, the considerable variation that is pointed out by the review of the ways in which IA is deployed in the teaching of anatomy hinders the objective assessment of its effectiveness and its comparison with other pedagogical methods. In this regard, a relative standardization could be useful. As a simple example, a very basic and practical test using a medical image could be systematically performed in each curriculum:

1. What kind of image is this? (X-Rays, US, CT, MRI…)
2. Are you able to orientate this image (as an anatomical picture)?
3. Are you able to name the anatomical structures? (and their anatomical relationships?)
4. Is this image a normal one?

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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