REVIEW

Value of Medical Imaging in Anatomy Education for Medical Undergraduates: A Narrative Review

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Abstract

Objective: To review the educational value of radiological imaging in undergraduate anatomy teaching and to explore the role of different imaging modalities in enhancing anatomical knowledge and clinical correlation in modern medical curricula.

Methods: A narrative review was conducted using peer-reviewed literature, focusing on anatomy, radiology, and medical imaging education. Relevant publications focusing on the educational applications of plain radiography, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), mammography, barium studies, digital image processing software, 3-D reconstruction, and artificial intelligence were analysed and integrated.

Results: The literature consistently highlights that medical imaging complements traditional anatomy teaching, allowing students to visualise human anatomy in different ways and understand 3-D anatomical relationships. Standard plain radiography enhances understanding of bones and joints, as well as thoracic and abdominal structures, while CT and MRI improve knowledge of cross-sectional and soft-tissue multiplanar anatomy. Ultrasound allows real-time visualisation of living anatomy, while mammography and fluoroscopic contrast studies enhance the understanding of breast, gastrointestinal, and genitourinary anatomy. Digital DICOM image display software, three-dimensional reconstruction, and emerging artificial intelligence applications increase spatial perception, student motivation, clinical reasoning skills, and self-directed learning.

Conclusion: Medical imaging has become an important adjunct to undergraduate anatomy education. Integrating imaging with cadaveric dissection and traditional teaching methods improves anatomical understanding, facilitates clinical application, and prepares medical students for contemporary medical practice. A well-balanced, imaging-integrated curriculum provides a more meaningful and clinically oriented approach to learning human anatomy.

Keywords: anatomy education; medical imaging; radiological anatomy; undergraduate medical education; radiology

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Introduction

Traditionally, anatomical knowledge is regarded as a cornerstone of preclinical and clinical medical education because a better understanding of human body structure is essential for the interpretation of disease processes, physical examination, and procedural skills, including surgical skills (1). In the sixteenth century, the Italian anatomist Andreas Vesalius revolutionised the study of human anatomy by introducing human cadaveric dissection, marking the beginning of a new, modern era of Western medicine (Figure 1) (2). Since then, cadaveric dissection, together with textbook-based learning, has remained a foundation of anatomy education for medical students.

While cadaveric dissections provide valuable tactile and spatial experience, modern educational challenges, including reduced curriculum time, increasing student numbers, ethical considerations, and resource limitations, have increasingly encouraged alternative approaches. Therefore, modern anatomy curricula increasingly emphasise clinically relevant, technologically advanced integrated learning approaches (1- 4).



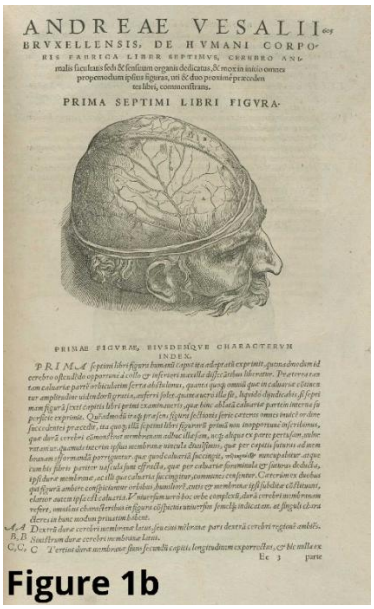


Figure 1: Historical foundations of modern anatomy education.
1a: Portrait of Andreas Vesalius (1514–1564), whose pioneering work established human cadaveric dissection as the foundation of modern anatomical science.
1b: An anatomical illustration from De humani corporis fabrica (1543) that illustrates the detailed anatomical observations that revolutionised the teaching of human anatomy. Source: Wikimedia Commons (Public Domain).

Evolution of Anatomy Teaching and the Emergence of Imaging-Based Education

Advances in medical imaging have not only improved patient care but have also changed traditional approaches to anatomy teaching. In modern clinical practice, non-radiologist physicians in nearly all major specialties and subspecialties routinely interpret standard plain radiographs, computed tomography (CT) scans, magnetic resonance imaging (MRI) scans, and ultrasounds, including point-of-care ultrasound (POCUS) (5).

Therefore, early exposure to imaging may help students correlate anatomical knowledge with real clinical scenarios. This may also encourage some students to consider radiology

as a future career (3). Unlike cadaveric specimens, medical imaging demonstrates anatomy in living individuals and allows appreciation of normal anatomical variations, movement, physiological relationships, and pathological changes, thereby providing a more comprehensive understanding of living anatomy (2).

Furthermore, due to recent advances in technology and web-based systems, students and educators can easily access electronic imaging resources without being physically present in the dissection theatre or lecture hall. This has expanded opportunities for anatomy learning beyond conventional educational methods through online image databases, DICOM viewing software, virtual dissection platforms, and digital learning resources (2, 5, 6).

Radiological anatomy teaching aims not to replace traditional approaches but to complement them by strengthening the three-dimensional (3-D) understanding of the body and promoting clinically oriented learning. Therefore, the incorporation of medical imaging into undergraduate anatomy education has attracted considerable worldwide interest (5, 6)

Imaging Modalities Used in Anatomy Education

Plain Radiography

Plain radiography is the initial imaging modality introduced to medical students during anatomy education. X-rays help students identify bones, joints, certain soft-tissue structures, and normal anatomical landmarks in a format commonly experienced in everyday clinical practice (2). In musculoskeletal teaching, radiographs improve understanding of osteology and landmarks, joint anatomy, the actual orientation of bones, and the correlation of bones with pathologies such as fractures and dislocations (2). Chest radiographs are the most commonly performed medical images worldwide (7). In thoracic anatomy, chest radiographs help students identify the lung fields, pulmonary fissures, trachea, main bronchi, cardiac borders, mediastinum, ribs, and diaphragms. Correlating these radiographic appearances with cadaveric specimens improves the interpretation of normal thoracic anatomy. This therefore facilitates the interpretation of common chest pathologies, such as lung collapse, pleural effusion, pneumothorax, cardiomegaly, mediastinal widening, and diaphragmatic paralysis. Similarly, abdominal radiographs can be used to assess the distribution of intra-abdominal gases, the anatomical location of the small and large intestine, the contour of the organs, and the bony structures of the abdomen and pelvis. A better understanding of abdominal radiographic anatomy will help students identify key pathological signs, including bowel obstruction, pneumoperitoneum, abnormal calcifications, and soft-tissue masses. Consequently, conventional radiography provides an excellent link between basic anatomical knowledge and its clinical application (Figure 2) (8). Mandal *et al.,* demonstrated that incorporating radiographs into anatomy teaching improves anatomical understanding, promotes long-term memory, spatial awareness, clinical associations, and confidence in interpreting images frequently used in routine clinical practice (9).

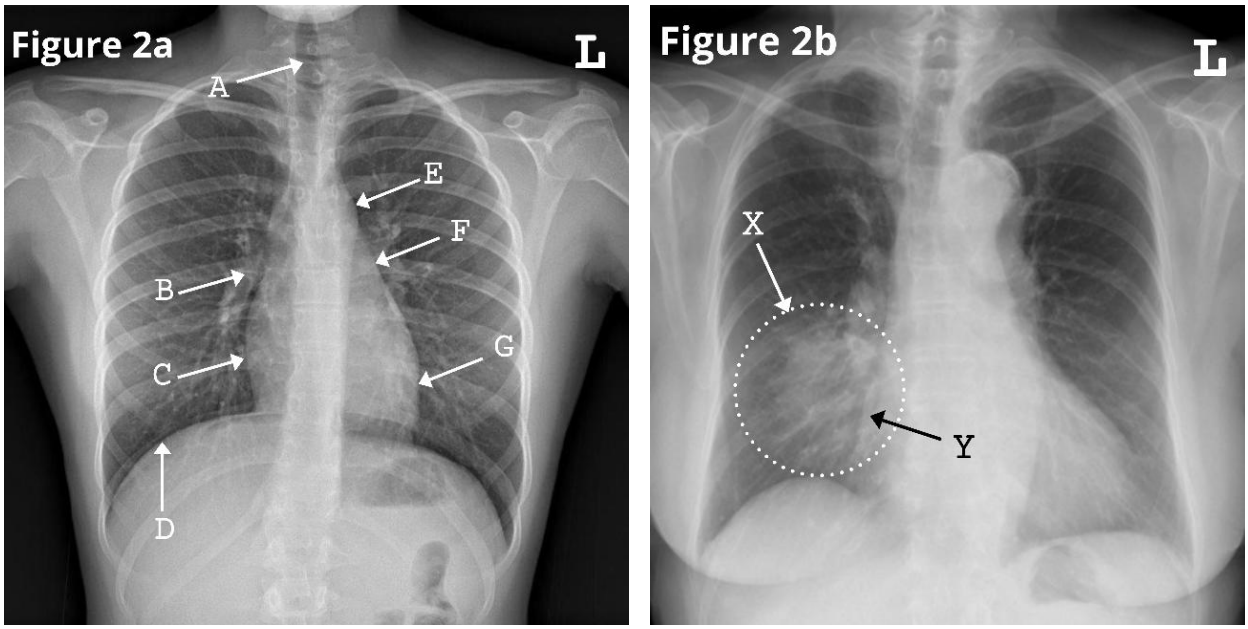


Figure 2: Conventional chest radiography as a tool for teaching normal and applied thoracic anatomy. Students first identify the normal thoracic anatomical landmarks on a posteroanterior chest radiograph. 2a: trachea (A), right pulmonary artery (B), right ventricular border (C), right hemidiaphragm(D), aortic arch (E), left atrial appendage (F), and left ventricular border (G). They can then compare these findings with a pathological chest radiograph. 2b: demonstrates right middle lobe pneumonia (X) results in loss of the normal right heart border(Y) (silhouette sign). This comparison reinforces the understanding of normal radiological anatomy while demonstrating its clinical application, thereby improving anatomical knowledge, image interpretation, and diagnostic reasoning.

Ultrasonography

Ultrasonography is a cheap, bedside, safe and non-invasive imaging procedure commonly used in clinical practice. Currently, it is widely used by non-radiologists in emergency units, such as PoCUS, to guide catheters and cannulas during various vascular-related procedures and to assess free fluid in cavities, especially in the management of Dengue fever in tropical countries (10). Therefore, basic ultrasound anatomy knowledge is very important for medical students, as it helps them perform clinical activities confidently. Ultrasound has significant value in anatomy education because it allows real-time visualisation of living anatomy. Students can observe muscle movements, vascular pulsation, organ motion, and dynamic relationships between structures (11,12). PoCUS has expanded educational opportunities by enabling bedside anatomy teaching. Students can visualise the liver, kidneys, thyroid gland, blood vessels, muscles, tendons, and abdominal organs, and their relationships to other structures, directly with peers or volunteers. This active participation increases students' engagement and supports experiential learning (Figures 3) (12).

Value of Mammography in Breast and Axillary Anatomy Education for Medical Undergraduates

Mammography is an important imaging tool for teaching breast and axillary anatomy. It shows the breast parenchyma, skin, nipple, retromammary space, pectoral muscles, and axillary tail of Spence (13). Mammograms also demonstrate the relationship between breast tissue and axillary lymph nodes, which is important in breast cancer assessment (13). A

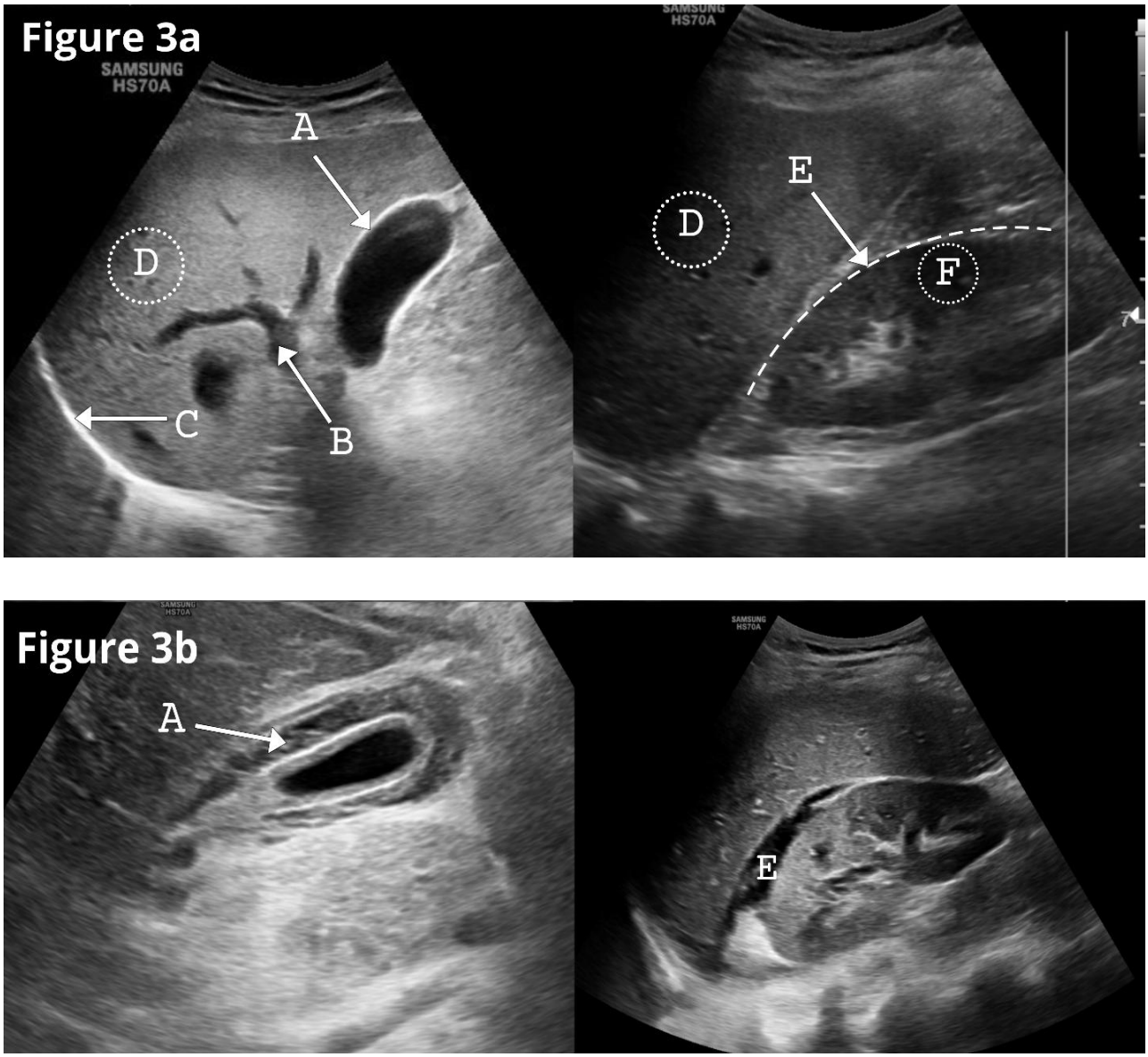


Figure 3: Ultrasonography as a tool for teaching normal and applied abdominal anatomy.
3a: Normal abdominal ultrasound demonstrating important anatomical landmarks. Students can identify the gallbladder (A), portal vein (B), diaphragm (C), liver (D), hepatorenal recess (Morison's pouch) (E), and right kidney (F). Real-time ultrasonography enables students to appreciate the anatomical relationships between these structures in living individuals and correlate them with gross anatomy. 3b: Ultrasound of a patient with dengue haemorrhagic fever demonstrating gallbladder wall thickening (A) and free fluid within the hepatorenal recess (Morison's pouch) (E). By comparing it with normal examinations, students learn normal abdominal anatomy and recognise early pathological changes detected in routine clinical practice. This integrated approach enhances anatomical knowledge and understanding of common ultrasound findings.

better understanding of normal mammographic anatomy enables students to recognise common abnormalities encountered in clinical practice, such as masses, calcifications, architectural distortion, and axillary lymphadenopathy.

Value of Barium and Other Contrast Studies in Anatomy Education for Medical Undergraduates

Barium and other contrast studies are useful tools for teaching the anatomy of the gastrointestinal and genitourinary systems. These examinations outline the lumen of hollow organs, allowing one to understand their shape, position, and anatomical relationships. Barium swallow studies demonstrate the pharynx, oesophagus, gastro-oesophageal junction, and stomach, while barium meal and follow-through examinations visualise the stomach and small intestine (14). Barium enema studies provide detailed views of the colon, caecum, appendix, and rectum. Anatomical structures such as haustrations and valvulae conniventes are well visualised in these examinations (14). Other contrast examinations, such as intravenous urography, help students understand the pelvicalyceal anatomy and the ureter pathway in relation to the spine. A male urethrogram is a better investigation for evaluating the normal anatomy of the male urethra. Correlation of these contrast studies with gross anatomy enhances spatial understanding and helps students to recognise common clinical abnormalities.

Value of Computed Tomography in Anatomy Education for Medical Undergraduates

Unlike plain X-rays, it provides detailed sectional images of the human body in three different planes: axial, frontal, and lateral. This contributes to a better understanding of the 3-D relationships between organs and surrounding structures (15). Modern DICOM viewing software enables students to scroll through image slices, rotate structures, especially skull bones, and examine 3-D anatomy from different views (Figures 4). These technologically enhanced tools help students to gain a better sense of complex anatomical relationships and spatial orientation (5,16). In neuroanatomy, CT images help to identify the cerebral hemispheres, ventricles, basal ganglia, brainstem, cerebellum, skull bones, and intracranial spaces.

A better understanding of normal CT anatomy enables the recognition of common conditions, such as various types of intracranial haemorrhage, cerebral infarction, cerebral oedema, and skull fractures, in clinical practice. In thoracic anatomy, CT clearly demonstrates the lungs, mediastinum, heart, major vessels, airways, ribs, and vertebrae. Similarly, abdominal CT allows detailed visualisation of the liver, spleen, pancreas, kidneys, bowels, abdominal vessels, and pelvic organs (17). Correlating CT images with cadaveric anatomy improves spatial understanding and prepares students to interpret cross-sectional imaging routinely encountered pathological conditions in modern clinical practice (Figures 5) (17).

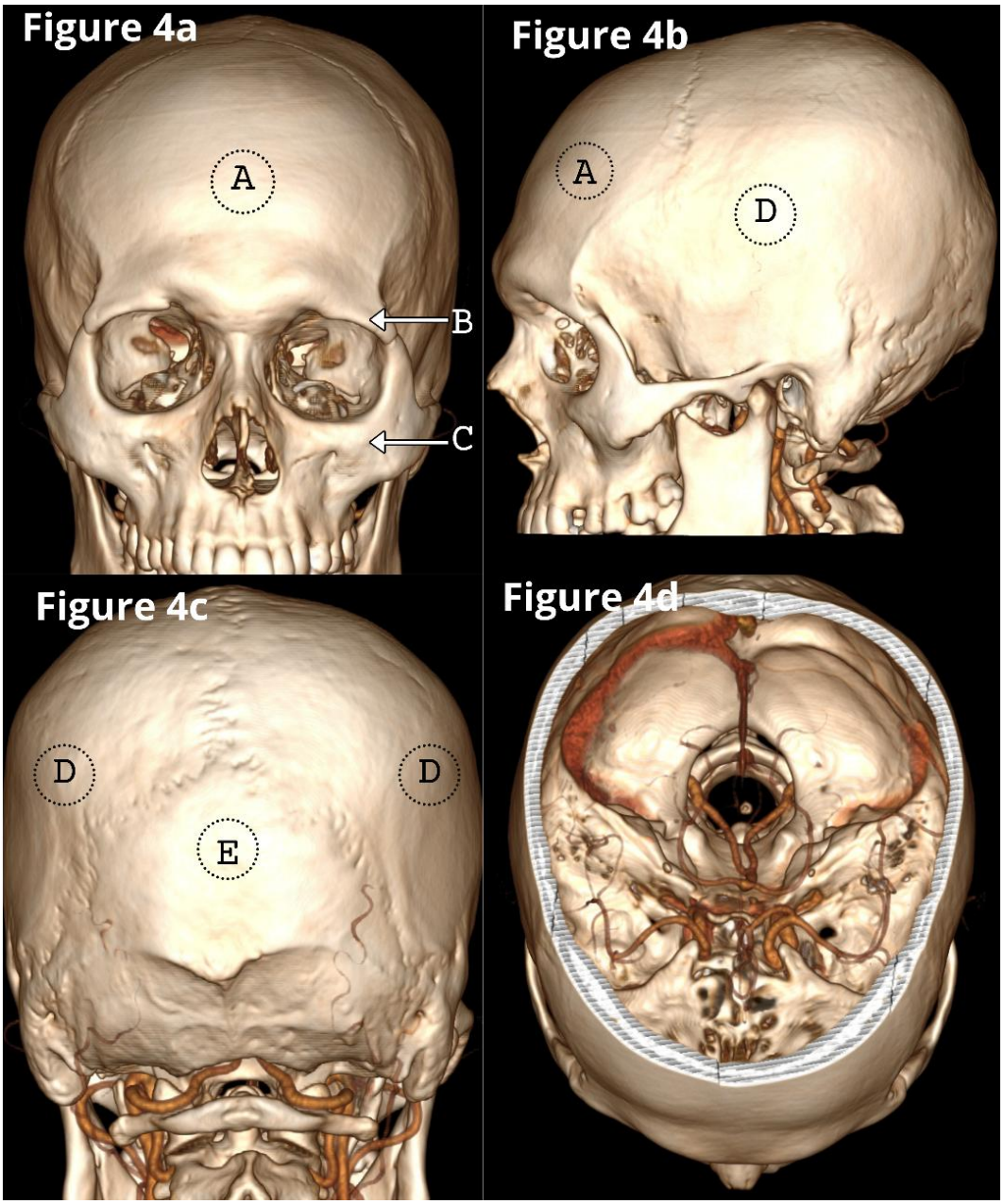


Figure 4: Three-dimensional CT reconstruction as a tool for teaching skull anatomy.
4 a-c: Three-dimensional (3-D) volume-rendered CT reconstructions demonstrate the normal bony anatomy of the skull from anterior, lateral, and posterior views. Using modern DICOM software, students can rotate the reconstructed images and examine the skull from multiple perspectives, thereby improving their understanding of complex three-dimensional anatomical relationships. For example, students can identify the frontal bone (A), zygomatic process of the frontal bone (B), maxilla (C), parietal bone (D), and occipital bone (E).
4d: The skull vault has been digitally removed using volume-rendering techniques, allowing visualisation of the internal cranial cavity. This view demonstrates the vertebral, basilar, and internal carotid arterial systems and their anatomical relationships to the skull base. Such interactive 3-D reconstructions enable students to explore anatomy from external and internal perspectives, complement cadaveric dissection, and improve spatial understanding of cranial anatomy.

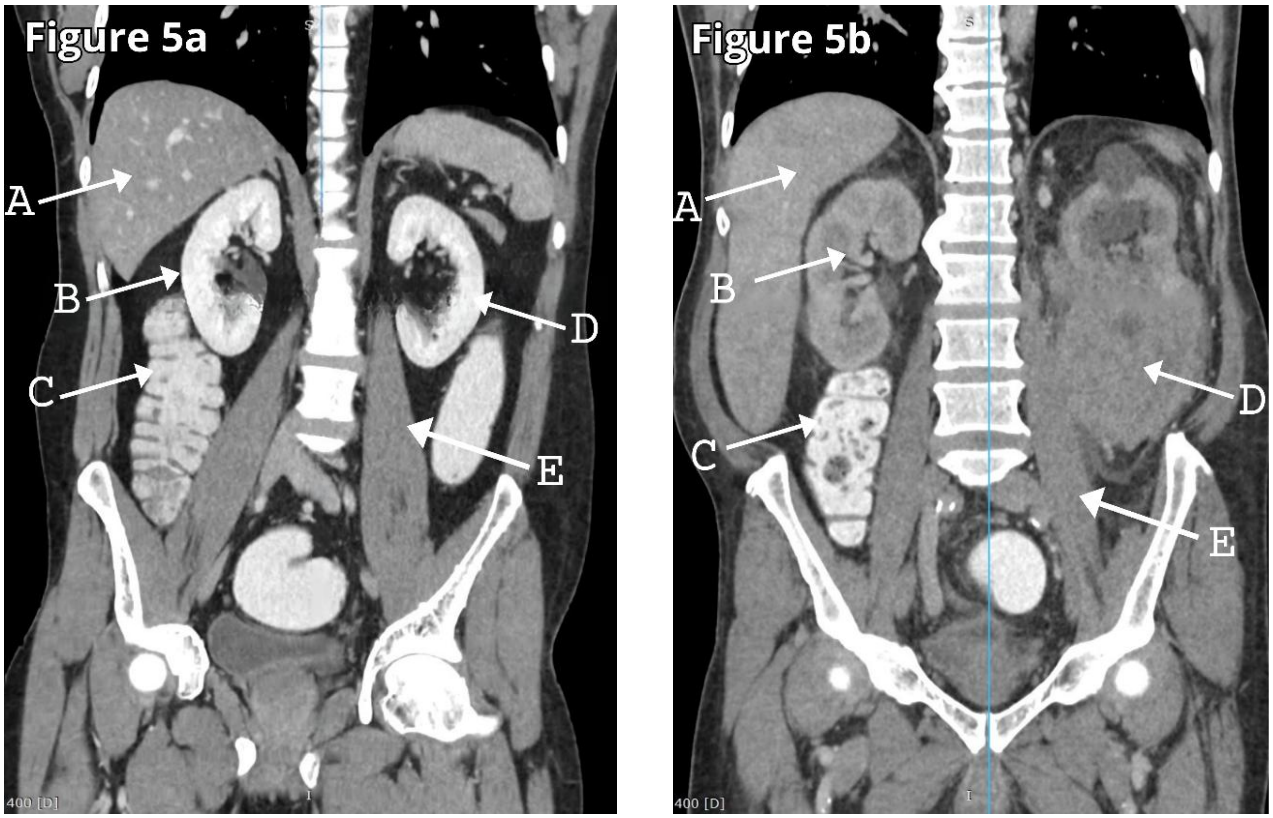


Figure 5: Coronal reconstructed CT as a tool for teaching normal and applied abdominal anatomy. 5a: Coronal contrast-enhanced CT demonstrates normal abdominal anatomy. Students can identify the liver (A), right kidney (B), ascending colon (C), left kidney (D), and left psoas muscle (E). Coronal reconstructed images provide a natural view of the anatomical relationships between abdominal organs and complement the understanding gained from cadaveric dissection. 5b: Coronal contrast-enhanced CT of a patient with a large left renal cell carcinoma (D). Comparison with the normal CT image demonstrates distortion of the normal renal anatomy and alteration of the relationships with adjacent structures, including the left psoas muscle (E). This comparison helps students appreciate the importance of normal anatomical relationships and understand how disease processes can distort tissue planes and invade neighboring structures. Integrating normal and pathological CT images improves anatomical knowledge and clinical image interpretation

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Value of Magnetic Resonance Imaging in Anatomy Education for Medical Undergraduates

Magnetic resonance imaging (MRI) is an excellent, radiation-free modality for evaluating neurological and musculoskeletal pathologies. In addition, it is used for teaching anatomy because it provides excellent soft tissue contrast and detailed visualisation of internal structures. In contrast to CT, which is especially valuable for the evaluation of bones and acute haemorrhage, MRI displays a more complete analysis of the brain, spinal cord, nerve roots, muscles, ligaments, cartilage and other soft tissues (1, 6). In neuroanatomy, MRI provides better identification of the cerebral grey and white matter, basal ganglia, internal capsule, thalami, brainstem, cerebellum, cranial nerves, ventricles, and major intracranial pathways. This allows students to understand complex neuroanatomical relationships and learn about common neurological disorders (Figures 6) (1, 6).

MRI is also highly valuable in musculoskeletal anatomy. It displays muscles, tendons, ligaments, articular cartilage, menisci, and intervertebral discs with excellent detail. MRI is very useful in complex joints such as the shoulder, hip, and knee. Modern DICOM software enables students to review images in multiple planes and create three-dimensional visualisations, enhancing spatial understanding (1, 5, 6).

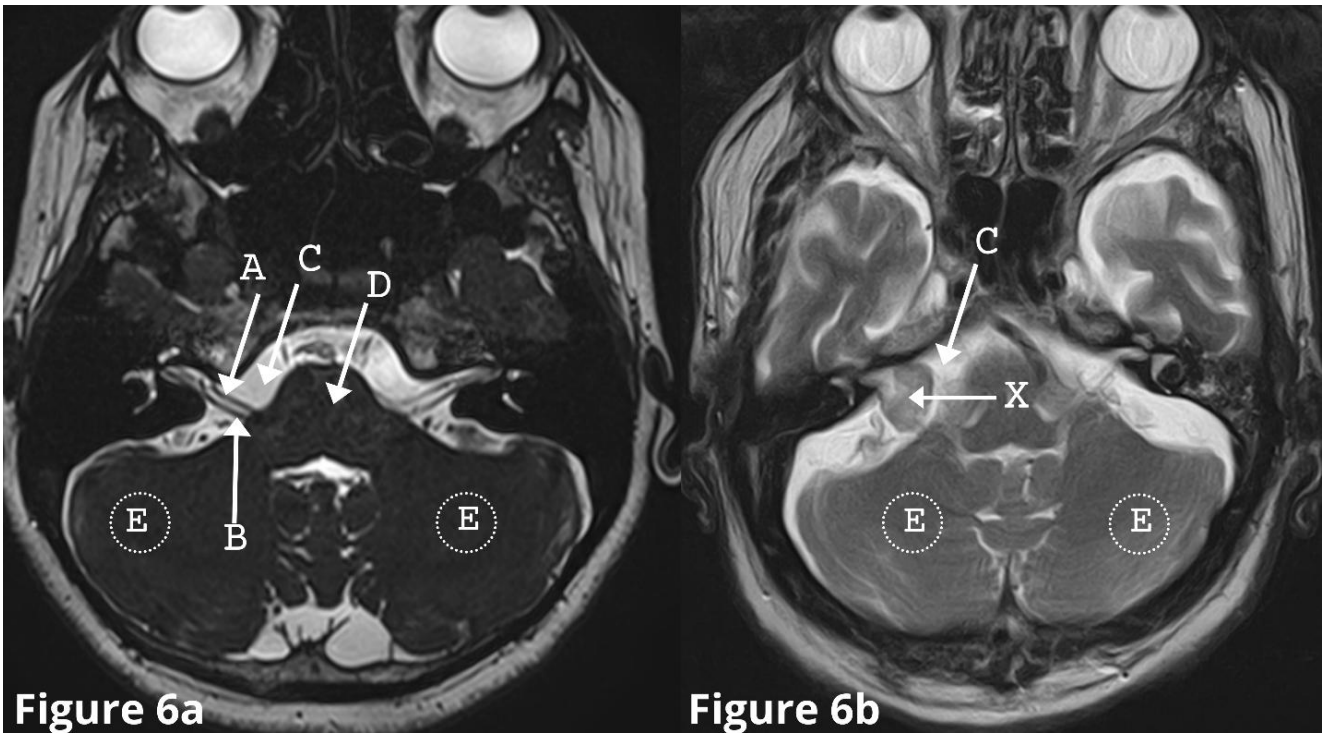


Figure 6. MRI as a tool for teaching normal and applied neuroanatomy of the cerebellopontine angle. 6a: Axial T2-weighted MRI demonstrating the normal anatomy of the cerebellopontine (CP) angle and internal auditory meatus (IAM). MRI provides superior soft tissue contrast, allowing students to learn the complex relationships of the cranial nerves. Students can identify the facial nerve (A), the vestibulocochlear nerve (B), the cerebellopontine angle cistern (C), the pons (D), and the cerebellum (E). Understanding the normal arrangement of the facial and vestibulocochlear nerves within the IAM provides the basis for recognising pathology in this region. 6b: Axial T2-weighted MRI demonstrating a right vestibular schwannoma (X) extending into the internal auditory meatus and cerebellopontine angle. Comparison with normal MRI illustrates distortion of the normal anatomy and compression of the adjacent cranial nerves. This allows students to appreciate the clinical importance of CP angle anatomy and understand how lesions in this region produce characteristic neurological manifestations. Comparing normal and pathological MRI findings strengthens their neuroanatomical knowledge and clinical image interpretation.

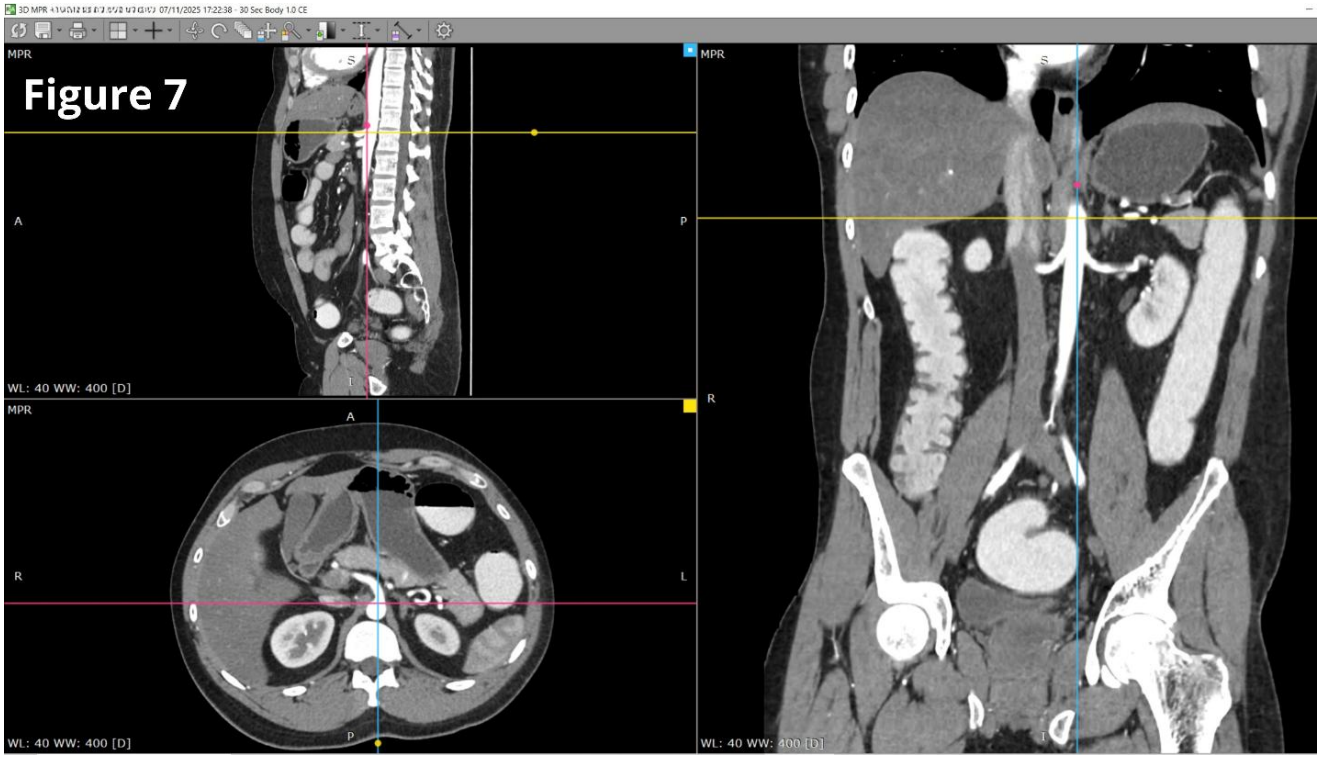


Figure 7: Modern DICOM software enables simultaneous viewing of CT images in the axial, coronal, and sagittal planes using multiplanar reconstruction (MPR). Students can scroll up and down through the image slices and correlate anatomical structures across different planes. This improves 3-D spatial understanding and, therefore, facilitates the interpretation of cross-sectional imaging in clinical practice.

Educational Benefits of Medical Imaging in Anatomy Teaching

Medical imaging offers many educational advantages well beyond simple identification of anatomical structures.

One of the major advantages of learning radiological anatomy is its ability to correlate anatomical knowledge to clinical practice. Medical students face a dilemma about the practical importance of learning a difficult as human anatomy. Medical imaging simply demonstrates how anatomical structures relate to various diseases, clinical examination, and patient management, thereby increasing its clinical relevance (2). When students understand the clinical relevance of anatomy, they become more engaged, resulting in greater motivation and better long-term retention of knowledge (18).

Imaging diagnosis also encourages vertical integration throughout the medical curriculum, rather than teaching anatomy as an isolated core science. It establishes a link between structural knowledge and pathology, surgery, emergency medicine, and radiology (19). Interactive learning activities, such as image interpretation, multiplanar image analysis using DICOM software such as RadiAnt, peer ultrasound scanning and clinical case discussions, improve self-directed learning (Figure 7) (5, 19).

Integration of Imaging into Undergraduate Curricula

Medical schools use different approaches to integrate radiological imaging into their anatomy curricula. Some introduce it in the first year, allowing students to learn about normal anatomy using standard radiographs, fluoroscopy, mammograms, CT, MRI, and ultrasound. Others introduce imaging later, usually during system-specific modules, after students have learned the basics of anatomy and physiology (20, 21). Some instructors use a spiral curriculum because it allows students to review basic anatomy concepts throughout the course while simultaneously learning about various pathologies through diagnostic imaging (21). Some of the common teaching methods for integrating radiological imaging include small-group case studies, problem-based learning, radiology laboratory exercises, online image databases, interactive image interpretation workshops, clinical case discussions, flipped classrooms, and infographic posters (15, 20, 21). All these methods promote active participation and clinical reasoning (15, 20). Close cooperation between anatomists, radiologists, and clinicians is essential for effective integration of radiological imaging into anatomy education (20, 21). Together, they can introduce imaging techniques at appropriate stages of the medical curriculum and help students better understand anatomy and its clinical applications. These teaching methods make learning more interactive and help students apply anatomical knowledge in clinical settings (Figure 8 and 9) (15, 20).

The RadFlash online repository developed for the e-Kelaniya learning management system contains nearly 200 image-based single best answer (SBA) cases. This radiology-based educational tool covers normal anatomy, radiological anatomy, and common clinical conditions. Each case combines medical images with clinical questions that require students to apply their knowledge of anatomy to diagnostic reasoning. This interactive learning method reinforces radiological anatomy, promotes self-directed learning, and assists students in integrating basic anatomical concepts with everyday clinical practice (Figure 8).

Infographic posters based on radiology were developed to supplement undergraduate anatomy teaching. Each poster focuses on a specific anatomical region. These posters integrate normal radiological anatomy with common pathological conditions encountered in clinical practice. The posters are displayed as 2 × 5 ft X-banners in common student areas, encouraging continuous self-directed learning beyond the classroom. Each infographic contains brief anatomical descriptions, labelled radiological images and key clinical points. An integrated QR code links to a detailed online learning resource containing explanations and additional images.

This innovative teaching strategy extends anatomy learning beyond the lecture hall, promotes self-directed learning, and strengthens the integration of radiological anatomy with clinical medicine (Figure 9).

Challenges and Limitations

Although the educational benefits of radiological imaging are well understood, some challenges to its widespread implementation remain.

1. Lack of teaching staff

One of the main problems is the shortage of radiologists in undergraduate medical education. In many medical faculties, only a few radiologists participate in teaching, and in some universities, radiologists are not involved at all (20, 22, 23). Furthermore, the lack of staff to teach anatomy and the rising number of

students forced radiologists to teach general anatomy and histology alongside radiological anatomy. It can be difficult to balance these educational responsibilities with clinical commitments, which may reduce the time available for structured radiology teaching.

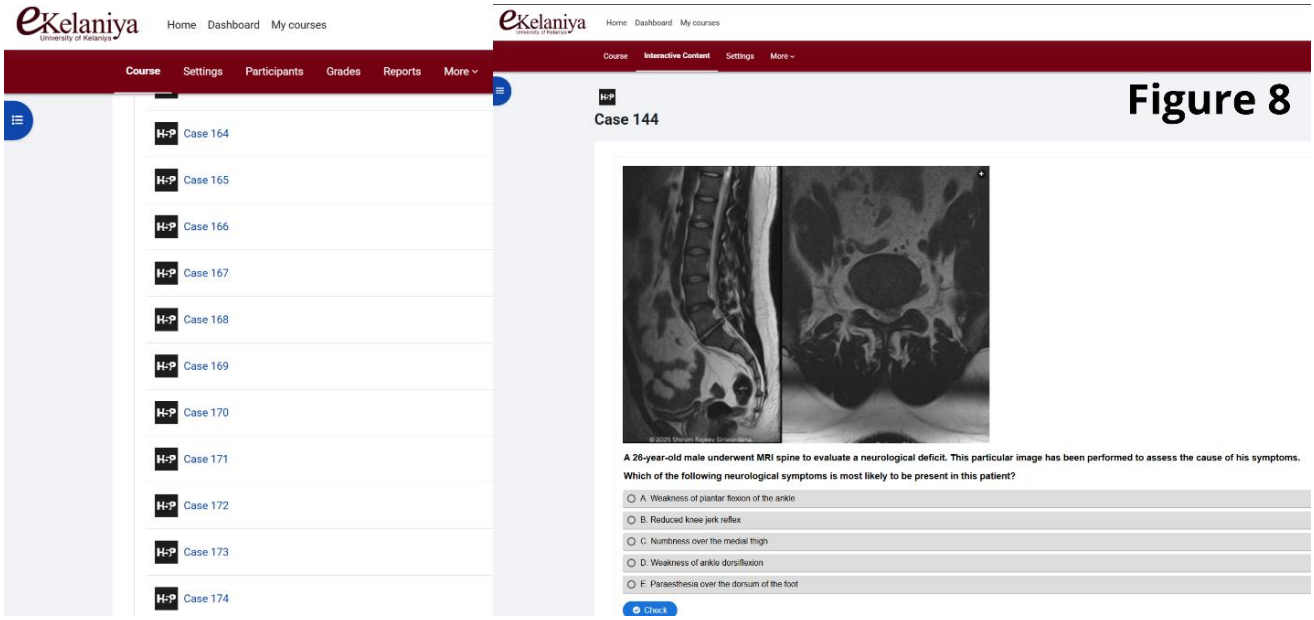


Figure 8: RadFlash: Image-based applied anatomy learning through an online repository.

2. Limited collaboration between departments

Effective integration of radiological imaging demands a common understanding among anatomists, radiologists, clinicians, and curriculum planners. However, such collaboration may not always be present. Imaging anatomy may not be effectively integrated due to poor communication and limited coordination between departments (20, 22, 24).

3. Limited resource

One major limitation is the constraints of resources, especially in low- and middle-income countries. There may be limited availability of imaging equipment, such as ultrasound machines, dedicated radiology workstations, DICOM viewing software, and adequate computer or multimedia facilities. These kinds of limitations hinder interactive, image-based learning and hands-on teaching (22, 24).

4. Limited time in the curriculum

Medical curricula are already crowded with basic science and clinical modules. Therefore, extra teaching time for radiological anatomy could be challenging task (20, 22, 24). The introduction of radiological imaging into the curriculum should therefore be carefully considered to avoid increasing the workload for students and teaching staff.

Radiological imaging should be used as a complementary teaching tool that reinforces anatomical knowledge rather than replacing traditional cadaveric-based teaching and learning (24, 25).

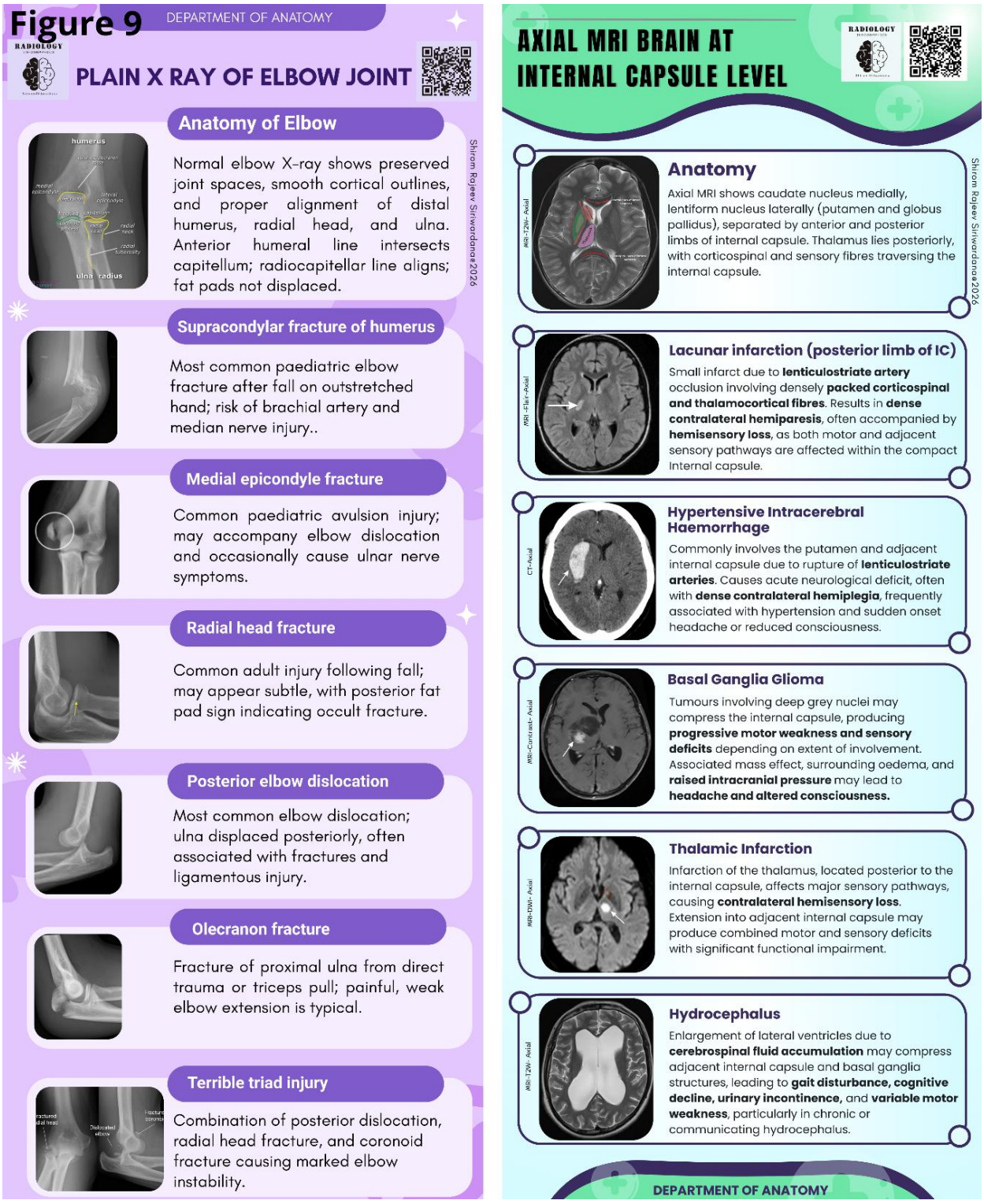


Figure 9: Radiology-based infographic posters as a supplementary learning tool for anatomy education.

Future Directions

Emerging technologies, such as artificial intelligence, virtual reality, and portable ultrasound that can be viewed on a tablet or smartphone, are expected to further improve anatomy education (20, 26). Artificial intelligence may assist with image interpretation and personalised learning, with automatic annotation of anatomical structures (20, 27). Portable ultrasound offers opportunities for bedside anatomy teaching. The expansion of open-access image databases and digital learning platforms may also improve access to imaging resources, particularly in low-resource settings (27).

Conclusion

Medical imaging has become an essential part of teaching and learning modern anatomy. It provides clinically relevant, interactive, visual learning materials that enhance anatomical understanding and, ultimately, promote long-term knowledge retention. X-ray, ultrasound, CT, MRI, and 3D imaging technologies all offer significant educational advantages. While radiological imaging should not replace traditional teaching methods, its integration into cadaver-based learning and clinical teaching offers significant educational benefits. As healthcare increasingly depends on imaging, early exposure during undergraduate education will better prepare future doctors for clinical practice.

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Availability of data and materials: Acquired DICOM medical images during the current review are available from the corresponding author upon reasonable request. The subject's identifying information was removed from the radiology images.

Conflicts of Interest: The authors declare no conflict of interest.

Ethical Approval: Ethical approval was not considered, as my work is a narrative review. However, I have secured informed consent to publish radiological images from each patient. Additionally, I have intentionally removed identifying information from the radiology images. Consent was obtained in the local and English languages and fully completed consent forms are available upon request.

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