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ORIGINAL ARTICLE

A practical description and student perspective of the integration of radiology into lower limb musculoskeletal anatomy

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Abstract
Background Anatomy educators are increasing their utilisation of radiology in anatomy education in line with growing requirements for undergraduate radiology competency and clinical need.
Aims We aimed to evaluate student perceptions of radiology and to outline the technical and academic considerations underlying the integration of radiology into musculoskeletal practical anatomy sessions.
Materials and methods The formal integration of radiology into anatomy practical sessions took place over a 5-week period during the lower limb musculoskeletal component of the anatomy course taught to first-year medical students. During practical sessions, students were required to rotate between aligned audio-visual radiology presentations, osteology/anatomical models, and prosection/dissection learning stations. After completing the course, students were invited to complete a survey to establish their opinions on radiology as a mode of learning and their satisfaction with radiological integration in anatomical practical sessions.
Results Most students were not familiar with radiology prior to attending our university. All our students agreed or strongly agreed that learning to read radiographs in anatomy is important and most agreed that radiology is a valid assessment tool. Sixty percent stated that radiology facilitated their understanding of anatomy. The majority believed that radiology was best suited to clinically relevant anatomy and X-rays were their preferred learning tool.
Conclusions The practical approach to integrating radiology into undergraduate musculoskeletal anatomy described here did not place strain on existing academic resources. Most students agreed that radiology should be increased in anatomy education and that learning to understand radiographs in anatomy was important for clinical practice.

Keywords Radiology · Lower limb · Musculoskeletal · Anatomy · Undergraduate · Medicine

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Introduction

A comprehensive understanding of anatomy remains fundamental to preparing medical students for clinical practice, as it forms the foundation for the understanding of disease and treatment strategies [1–3]. Anatomy is traditionally taught in the first 2 years of preclinical training and is delivered by lectures, small group learning, cadaveric dissection, prosection, or combined approaches of these [4]. While cadaveric-based dissection/prosection teaching remains at the core of anatomy teaching [5–7], modern digital and pedagogical anatomy resources have assisted educators in promoting discipline-specific teaching [8–16]. In particular, technological advances in medical imaging are greatly enhancing diagnostics and radiology is gradually becoming an integral component of preclinical training [3, 8, 16–23]. For example, the rapid uptake of mobile technologies and their integration with pre-existing Picture Archiving and Communications Systems (PACS) has revolutionised the practice of radiology and access to diagnostic images among healthcare professionals.

However, while the integration of radiology into academic anatomy teaching has been documented as early as 1950 [24], modern digital platforms have only recently facilitated its use in formal teaching and its amalgamation into curricula varies amongst institutions.

Radiology appears main-stream in the United States (US) (80 %), Canadian (92 %), Australian, and New Zealand (100 %)-based medical schools, which utilize at least some form of radiological imaging as part of their undergraduate curriculum [25–28]. Moreover, a survey of 21 British and Irish universities performed in 2002 showed that the majority of medical schools are delivering anatomy content via integrated curricula involving radiology [17]. However, the extent of radiology's involvement in undergraduate curricula is often truncated, inconsistent, and its vertical integration varies widely. For example, the European Society of Radiology showed that only 26 % of 34 surveyed European countries integrated radiology into first-year medicine [29], while US medical schools devoted an average of just 5 % of teaching time to radiology [30]. Radiology, including X-ray, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound enhances student understanding of three-dimensional (3D) anatomy [2, 23, 31–36], demonstrates the immediate relevance of anatomical learning and bridges the gap between preclinical teaching and professional practice [37–39]. Moreover, incorporating radiology into undergraduate anatomy teaching prior to formal clinical training has been shown to enhance interpretation of vital radiographic material in clinical years [40–42]. The necessity for more formalised and consensus-led integration of radiology in anatomy education is recognised by both educators and clinicians alike [7, 43–49]. However, despite the perceived advantages, many anatomy departments are failing to consistently engage their anatomy syllabus with radiology components [29, 50, 51], which is most likely a result of increasing student demand, declining teaching resources and potentially paucity of radiology expertise [3, 8, 17–21]. In addition, some educators feel that anatomy teaching should exclusively focus on clinically relevant anatomy and the interpretation of radiographs [52, 53], while others suggest that a blended approach is necessary, where the traditional anatomy teaching should place greater emphasis on radiology [38, 54–58]. Moreover, the role of the radiologist in undergraduate anatomy education, proposed delivery methods or recommended time allocation to radiology teaching remain unclarified, especially in the context of specific modular anatomy components, such as musculoskeletal anatomy.

In this communication, we describe the formal integration of radiology into anatomy lower limb practical sessions, without placing strain on existing teaching resources. We evaluated student opinion of the integration of clinically relevant and structural/functional anatomy, X-ray, CT, MRI, and ultrasound radiology into undergraduate lower limb musculoskeletal anatomy laboratory sessions. The class concerned consisted of 181 students who were divided into 2 groups of 90 and 91 to attend practical sessions in the dissection theatre (DT) on consecutive days. The DT was separated into 10 learning stations. Each station comprised of a donor body, a display area for anatomical models, and a 36-inch monitor running an android operating system. Academic staff involved in the delivery of practical sessions consisted of four Anatomy Demonstrators and two Anatomy Lecturers. The musculoskeletal anatomy taught within our department currently consists of a 10-week semester, with 5 weeks each devoted to upper and lower limb anatomy. For the latter, the first four sessions pertained to one element of lower limb anatomy and involved integrating traditional approaches, including prosection, dissection, cross-sectional plates, plastic models, and osteology specimens with key radiology images that necessitated student interaction though identifying important anatomical features. The final practical was a revision session which involved the understanding of musculoskeletal pathologies. Our laboratory methods are described on a week-to-week basis and our findings are discussed in relation to current musculoskeletal anatomy teaching practices and the student learning experience.

Fig. 1 Sample presentation slides, anatomical specimen, and prosections from practical sessions 1–5. **a** *Week 1* X-ray of the pelvis, including proximal femurs and accompanying questions. Osteology of human pelvis and prosection of gluteal region. **b** *Week 2* MRI of the Knee and accompanying questions. Knee joint osteology and prosection of anterior knee, showing quadriceps muscles and patellar tendons. **c** *Week 3* X-ray of the tibia and fibula and accompanying questions. Osteology of tibia and fibula and distal tibiofibular joint. Prosection of anterior and lateral compartments of leg. **d** *Week 4* X-ray of the ankle/foot and accompanying legend. Osteology of the foot and sub-talar joints. Prosection of the anterior compartment of leg and foot. **e** *Week 5* X-ray of the lower limb. Osteology of the lower limb. Prosection of anterior compartment muscles of thigh and leg ▶

Materials and methods

The integration of radiology into lower limb practical sessions

The study was performed over a 5-week period from weeks beginning 2nd November to 4th December 2015, during which students participated in 5 × 3-h practical anatomy sessions in the DT based on all aspects of lower limb musculoskeletal anatomy. In groups of eight and nine, students were assigned to each of the learning stations in


Radiology
Osteology / anatomical model
Dissection / prosection
A
A T S Q B P C O R R U N M D L G I E J F H K
Identify A - U
B
A M L B D H K E J C I
Identify A – M
F G
What is the function of E and K?
C
A L B K C J D I H E G F
Identify A – L
What lies at E?
What nerve is related to D?
D
A B C I H D E G F
Identify A – I
Describe movements
What ligaments stabilise these joint?
E
Review lower limb landmarks
What vessels are important when considering repair of hip fractures?
What classification system is used for ankle fractures?

the DT. Students were then divided into three groups of three individuals at each station, which were rotated every 45 min between three practical learning components; namely (1) a cadaver, (2) osteology/plastic models, and (3) an audio-visual (AV)-based radiology presentation (for samples of each learning component, see Fig. 1). A final 45 min was available after these rotation components for small group tutorials, which were delivered by anatomy staff. Prosections on one lower limb were performed in advance by staff, offering students the opportunity to dissect structures in the remaining lower limb during the cadaver component of the practical session. Radiology was integrated into practical classes through PowerPoint (Microsoft, version: 14.0.7166.5000) presentations displaying plain film X-rays, CT, MRI, angiography, and ultrasound. These were uploaded to monitors at each station. Students had the ability to control and progress the presentation using remote controllers for each monitor. Each presentation consisted on average ten slides incorporating various radiological modalities demonstrating lower limb structures relevant to each week's learning objectives (Table 1). Content for the first 4 weeks consisted of non-pathological images of bones, muscles, tendons, ligaments, and vessels. Each image was first presented in an unlabelled format followed by a labelled version, and short answer questions were included with some of the slides. For example, an X-ray of the proximal femur included an arrow pointing to the lesser trochanter, students were asked to identify the bony prominence and to name the muscle attached to it. The final practical was dedicated to gross anatomy revision, and pathological images were included.

Evaluating the opinions of students toward radiology integration

After the final practical session, 181 first-year medical students were invited to complete an online anonymised survey to establish their attitudes towards the integration of radiology into lower limb anatomy. The survey was reviewed and approved by the local ethics committee of TCD. The survey instrument was a questionnaire consisting of ten independent, multiple choice questions that collected demographic data and sought to gauge student attitudes towards radiology and to measure their perceived benefit of radiology in anatomy education. Demographic questions determined the age range, gender, and region of origin of participants. Radiology questions were designed to determine (1) whether students had experience in radiology prior to attending our institution, (2) whether students enjoyed using radiology when learning anatomy, (3) whether radiology improved their understanding of anatomy during practical sessions, (4) which radiological modality they most preferred, (5) what type of anatomy was most enhanced by radiology, (6) whether radiology is a valid assessment tool in anatomy, and (7) their perceived importance of radiology for use in clinical practice. To analyse demographics and non-scalar survey responses, we tabulated data collected using Excel (version 14.0, Microsoft Corp., Redmond, WA). For scalar Likert data, Pearson's Chi-squared (χ^2) tests were performed to assess significant deviations in preferences from chance deviations using the Statistical Package for Social Scientists (version 22, IBM Corp., Armonk, NY). Data were

Table 1 Suggested weekly timetable covering lower limb syllabus over a 5-week period

	Radiology station (45 min)	Osteology station (45 min)	Cadaver station (45 min)
Week 1	Labelled and unlabelled X-ray, MRI, and CT of the hip joint and pelvis	Bony anatomy of the pelvis, proximal femur, and hip joint	Dissect the gluteal region, hip, and posterior thigh. Review prosections of the gluteal region and posterior thigh
Week 2	Labelled and unlabelled X-rays of the femur. MRI and CT of the knee joint	Bony anatomy of the distal femur, patella, proximal tibia, and knee joint	Dissect the anterior thigh, medial thigh and knee joint. Review prosection of the same region, including nerves and vessels of the thigh
Week 3	Full length X-rays of the tibia and fibula. Lower limb angiograms	Proximal and Distal Tibiofibular joints and bony anatomy of the ankle joint	Dissect anterior and posterior compartments of the Leg, including muscles, nerves, and vessels. Review prosection of the same region on contralateral side
Week 4	X-rays, MRI, & CT of the foot and ankle. Include ultrasound achilles tendon	Bones of the foot and articulating surfaces of the sub-talar joints	Foot and ankle dissection, including sub-talar joints. Major vessels and nerves of the foot
Week 5	Lower limb radiology revision incorporating pathology; X-rays showing fractures, dislocation, and osteoarthritis. Angiograms showing emboli. Ultrasound demonstrating tendon rupture. CT complex fractures. MRI showing muscle tears and ligament damage	Revision of lower limb osteology	Revision of lower limb cadaveric anatomy

considered to be statistically different from chance expectations at $p < 0.05$.

Results

Demographics

One hundred and eighty-one first-year medical students were invited to complete an anonymised questionnaire. Eighty-nine students responded for a 49 % response rate. Forty-three percent of respondents were male and the majority were aged between 18 and 30 years of age (99 % of those surveyed) (Table 2). Seventy-two percent of respondents were European, while the remaining students originated from Asia, North America, Africa, and the Caribbean (Table 2).

Student opinion of radiology in practical anatomy education

Students were first asked whether or not they had experience of reading radiographs prior to attending our institution. The majority (84 %) stated that they had no prior experience in radiology ($\chi^2 = 40$, $df = 1$, $p < 0.0001$) (Table 3). Students were then asked if they enjoyed radiological integration in anatomy practical sessions. The overall pooled distribution of preferences showed a significant deviation from chance ($\chi^2 = 50$, $df = 3$, $p < 0.0001$), with 66 % stating that they enjoyed learning anatomy with radiology ($p < 0.0001$), while 32 % said that it depended on the topic (Table 3). Students were then asked if integrating radiology into anatomy practical sessions facilitated their understanding of anatomy. Students responses showed a significant deviation from chance expectations, indicating a clear preference in responses ($\chi^2 = 32$, $df = 2$, $p < 0.0001$). These responses also mirrored the previous question in that 60 % agreed that radiology facilitated their learning, while 31 % stated that it depended on the topic (Table 3). Students were then asked their preferred radiological method for anatomy learning. Clear preferences were demonstrated in their responses ($\chi^2 = 115$, $df = 4$, $p < 0.0001$). Interestingly, 66 % of students chose X-ray ($p < 0.0001$), while 17 % chose CT and 13 % chose MRI (Table 3). The remainder chose angiography (4 %) and ultrasound (1 %). Students were next asked which type of anatomy benefitted most from radiology integration. A clear preference was also observed in their responses ($\chi^2 = 155$, $df = 5$, $p < 0.0001$). A significant majority (73 %) chose clinical anatomy ($p > 0.0001$), 20 % chose osteology with the remainder choosing neuroanatomy (4.8 %) or muscular anatomy (2.4 %). No students selected vascular anatomy (Table 3).

We next determined whether students agreed or disagreed that radiology was a valid assessment tool in anatomy education. Sixty-seven percent agreed or strongly agreed, while 27 % were neutral ($\chi^2 = 69$, $df = 4$, $p < 0.0001$) (Fig. 2). Finally, we determined whether students agreed or disagreed that the ability to read radiographs is important for clinical practice. The overall pooled distribution of preferences showed a strongly significant deviation from chance expectation ($\chi^2 = 148$, $df = 4$, $p < 0.0001$). Of all five choices, 94 % either "agreed" or "strongly agreed" with the statement, while "strongly agree" had the largest number of expressed preferences (70.2 %; $p < 0.0001$) (Fig. 2).

Table 2 Student gender, age, and region of origin

Demographics	
Gender	*N* (%)
Male	38 (42.7)
Female	51 (57.3)
Age	
0–17	0
18–20	69 (77.5)
21–29	19 (21.3)
30–39	1 (1.1)
Region of Origin	
Africa	2 (2.3)
Asia	17 (19.3)
Europe	63 (71.6)
Middle East	0
North America/Canada	5 (5.7)
Other (Caribbean)	1 (1.1)

Discussion

Musculoskeletal injuries are amongst the foremost conditions observed in clinical practice [59, 60]. Findings from medical schools in the US, Canada, UK, and Ireland [48, 61–70] suggest that students are not adequately prepared in musculoskeletal medicine to meet clinical need partially due to a lack in undergraduate training, which is highlighted by the deficiencies in radiology understanding. Musculoskeletal anatomy is a major component of the anatomy curriculum at our university (an entire semester, year 1), yet the blending of radiology into existing anatomy teaching was seen as critical to advance our teaching in line with professional healthcare demand and students' need [7]. In the past, our department typically delivered practical anatomy teaching, which entailed informal radiological integration into donor-led practical sessions, in which students in groups of ten were assigned to a cadaver and

Table 3 Student's opinion of radiology in anatomy education

Survey answers	*N* (%)
Were you familiar with viewing radiographs prior to TCD?	
Yes	14 (16.1)
No	73 (83.9)
Did you enjoy learning anatomy using radiology?	
Yes	55 (65.5)
No	2 (2.4)
Depended on the topic	27 (32.1)
Did the integration of radiology into practical facilitate your learning?	
Yes	50 (59.5)
No	8 (9.5)
Depended on the topic	26 (31)
What was your preferred type of radiology?	
X-ray	55 (65.5)
Computerised tomography (CT)	14 (16.7)
MRI	11 (13.1)
Angiography	3 (3.6)
Ultrasound	1 (1.2)
Which type of anatomy do you feel radiology is best suited to teaching?	
Clinically relevant anatomy	61 (72.6)
Osteology	17 (20.2)
Muscular anatomy	2 (2.4)
Neuroanatomy	4 (4.8)
Vascular anatomy	0
Other (please specify)	0

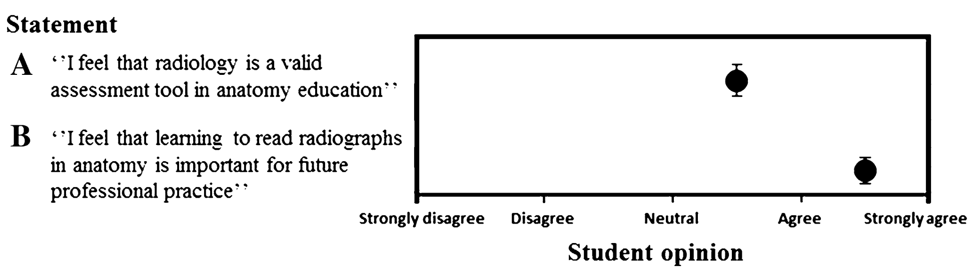

Fig. 2 Student opinion on radiology in assessment and in clinical practice. **a** Student opinion significantly demonstrated that radiology is a valid assessment tool in anatomy education ($p < 0.0001$). **b** The majority of significantly students agreed or strongly agreed that learning radiology is important for clinical practice ($p < 0.0001$)

were afforded the opportunity to dissect body tissues horizontally aligned to lecture topics, under the direction of an anatomy demonstrator and/or academic. Through small group modular donor-led learning our approach was to formally integrate selected lower limb MRI, CT, X-ray, angiograms, and ultrasound radiographs with prosected cadaveric tissues, osteology specimen, and anatomical models. This mode of team-based learning is a productive strategy that does not require additional teaching resources, yet has yielded success in a variety of anatomy curricula [71–75]. Moreover, consensus-led opinion amongst educators, students, and clinicians has shown that cadaveric assimilation is the most appropriate to formally incorporate radiology into anatomy curricula [35, 43, 48, 76]. In our study, the synergy between donor and radiology was enhanced by preparing prosected lower limbs and displaying osteology/anatomical models that aligned to radiographs, thus increasing time efficiency at each station [77, 78] and reducing dissection time, which often needs to be instructor led. This strategy contributed to a highly significant overall mark increase ($p < 0.0001$) for the practical examination element of the musculoskeletal component of the module, when compared with the previous year.

A number of important considerations need to be addressed when designing a multi-modal practical anatomy course, which seeks to integrate prosection, radiology, and the traditional teaching; namely, who is to source, prepare, and deliver radiology teaching on a continuous basis, and what technical facilities are required? Moreover, the vast majority of students surveyed as part of our and another study [23] had no prior experience of radiology, which will necessitate image interpretation and elements of diagnostic teaching, requiring a dedicated expert radiology contribution. The solution depends on the teaching philosophies and staffing arrangements of the medical school in question. While some may aim to up-skill a member of academic staff, others may engage radiologists as academic staff or may utilize hospital-based teaching resources. We chose to employ a radiology career oriented medically qualified member of teaching demonstration staff, whose mandate was to implement and teach the radiology components into practical anatomy sessions. Furthermore, weekly presentations were enabled primarily by an inclusive digital interactive display at each station. Our teaching facilities have been modernised in recent years, and authors appreciate that digital displays are not ubiquitous in all DTs and alternative presentation tools may need to be developed.

We found that the vast majority of students had no experience of radiology prior to attending our University. Although student's unfamiliarity with radiology represents an additional learning element, we found that they agreed that radiology is important for their profession, and that it should be utilized in examination periods to assess anatomical knowledge. This demonstrates an understanding of the benefits of radiological competence prior to clinical practice [79] and is reflected by the fact that 73 % of students felt that radiology was most suited to clinically relevant anatomy. We also report good student satisfaction with radiology and a positive perceived benefit in the context of anatomy education, which is in agreement with other studies [57, 76, 80–83]. However, up to a third of our respondents indicated that the benefits of radiology depended on the imaging modality and 65 % of students surveyed felt that X-rays were the best radiological modality for learning lower limb musculoskeletal anatomy, a finding previously reported for full body gross anatomy [76]. X-rays demonstrate bony landmarks on a 2D image, which are relatively easy to interpret and, therefore, useful for understanding osteology and points of muscle attachment, a key outcome in musculoskeletal anatomy. Less than 30 % of students preferred MRI and/or CT as a learning modality in anatomy, which may be related to the more complex nature of interpreting 3D structures and clinical issues [76]. A recent study outlining surgeons' opinions of radiology in anatomy education found that CT and MRI were most beneficial [7], which indicates that these modalities may need to be more formally introduced, perhaps, in didactic or specialised lectures taught prior to their amalgamation into donor-led practical sessions, especially when considering their benefits in improving the spatial relationships between structures in gross and arthrology-based musculoskeletal anatomy [55, 84]. In addition, aligning prosected lower limb joints and osteology specimen with selected X-ray, MRI, and CT radiographs greatly supported student appreciation of arthrology, though multiple planes of view [43, 81, 84–87]; while the opportunity to dissect these structures consolidated their understanding of biological variations, function, neuro-vasculature, and age-related pathologies [6, 7, 11].

Conclusion

In this report, we detail the process of integrating radiology into lower limb donor-led musculoskeletal anatomy practical sessions delivered to first-year medical students. Student opinion of the integration of radiology in anatomy practical sessions was positive as a learning tool in lower limb anatomy, as an assessment resource, and as a link to clinical practice.

Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest during the preparation of this manuscript or as part of its intended publication.

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