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Medical imaging education opportunities for junior doctors and non-radiologist clinicians: A review

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Abstract

Medical imaging plays a critical role in clinical decision-making across disciplines, and as such, there is frequent need for non-radiologist clinicians to interact with medical imaging. This review examines the literature about the delivery of medical imaging education to non-radiologist clinicians, spanning junior doctors, advanced trainees and specialists. Knowledge of medical imaging among non-radiologist clinicians is paramount to the quality of patient care, with calls for formal implementation of radiology education into non-imaging specialty training programmes. Overall, there is a demand across non-imaging disciplines for greater formalised medical imaging education. Concerns are raised that too great a reliance on informal methods of teaching radiology, for example in ward settings, results in greater variation in the quality and volume of educational opportunities and risks the perpetuation of erroneous attitudes and practices. The evolution of the medical imaging workplace and increasing utilisation of remote reporting has distanced the collaborative relationship between radiologists and their non-imaging colleagues, diminishing opportunities for ad hoc learning and engagement in larger formalised educational collaborations. Ideally, radiologists should be directly involved in the development and delivery of medical imaging education to post-graduate doctors to not only benefit patient care but also foster inter-specialty relationships and respect. Evidence supports the value of structured radiological teaching opportunities, including tutorials, lectures and electronic resources, in improving medical imaging skills among non-radiologist clinicians. There is wide scope for growth in the e-learning arena to address this demand for quality and accessible imaging education for our non-radiology colleagues.

Key words: doctors; education; e-learning; imaging; radiology.

Introduction

Medical imaging is a dynamic and evolving field, which has experienced significant growth and change over the last twenty years. Imaging data are now used throughout almost every clinical pathway, a trend which is accelerating with time reflecting the introduction of new technologies and innovative approaches across anatomical and functional imaging.[1] The changes in imaging are matched by shifts in the approach to education delivery to medical students, junior doctors and non-medical imaging specialists alike and include moves toward problem-based and team-based learning, increased digitisation and growth of online delivery. In parallel to these changes, radiology has transitioned from film-based reporting environments to electronic

reporting, and case volume has increased, often leading to reduced direct inter-disciplinary clinical contact.

This review aims to evaluate whether imaging education has kept pace with these changes and to explore how the educational needs of non-radiologists might be best served in our new and evolving environment.

Formal work-based opportunities for radiological education beyond medical school usually consist of hospital-based occasional didactic lectures and small group tutorials, or e-learning modules, which may be provided by employers or specialty training programmes. Teaching also occurs in informal settings including multidisciplinary team meetings, case-based discussions between clinical teams and a radiologist, or via review of clinical imaging for patients under the doctor's direct care. In specialist training programmes, key elements of imaging knowledge are formally incorporated as learning points in curricula, with courses and conferences often providing educational opportunities to address these imaging areas.

In this context, we consider the current state of medical imaging education for our non-medical imaging colleagues, including recently graduated junior doctors, registrars who have been enrolled in specialty training and non-radiologist specialists. We ask whether current approaches are 'fit-for-purpose' and therefore sufficient to meet their continuing professional development needs. We will also consider the role and responsibilities of radiologists in guiding and interacting with colleagues as we move further into the 'democratisation' and digitisation of medical imaging.

Who is teaching radiology to non-radiology clinicians?

There is great variation in the providers of medical imaging education, with differences observed between and across specialties and countries. The responsibility for providing medical imaging education commonly falls to non-radiology clinicians, with more senior doctors passing knowledge to their junior colleagues. The involvement of radiologists and other medical imaging experts is variable; however, many authors state that their input in the design and implementation of imaging educational opportunities would be optimal.[2-5]

Hospital-based learning environments

Surveys of North American surgical trainees[2,3] found the greatest proportion of post-graduate medical imaging education was provided by senior colleagues. In *Butler et al*,[3] 82% of surveyed surgical faculty and residents identified informal teaching from more senior surgery residents as the primary source of radiology education, whereas only 68% reported informal teaching from radiologists and 60% from radiology case conferences. Less than 1% of these doctors surveyed reported access to formal radiology education opportunities (such as hospital organised lectures, tutorials or e-learning modules) beyond medical school. Observers have suggested that reliance on this informal method of teaching, devoid of a curriculum and often without any radiologist input, results in greater variation in the volume and quality of the education and may risk perpetuation of erroneous attitudes and practices.[3]

Similarly, surveys of emergency department junior doctors found the majority of medical imaging learning opportunities occur during clinical practice, taught by more senior emergency colleagues including specialists and more senior trainees.[4] A single-centre study evaluating the value of collaboration between emergency medicine physicians and radiologists, demonstrated an improvement in interpretation error rates among emergency physicians following implementation of a feedback system. Plain films were double read by a radiologist within a 12-h time frame, with discrepancies ('errors') added to a newly developed teaching library and discussed at a monthly meeting.[5] This study found a decrease in their false negative rate from 3% to 0.3% over several iterations of the programme (false positive rates were not recorded) and argued for ongoing educational collaboration between the two specialties.

Building on medical school learning

An Australian study was recently published asking junior doctors (interns) to reflect on the adequacy of their radiology training in medical school. The survey found that the majority of undergraduate exposure to medical imaging was in an informal setting, with 52% reporting that the education provided did not adequately prepare them for post-graduate practice.[6] In an accompanying editorial, Mendelson and Taylor highlighted the frustrations they had encountered trying to implement a radiology curriculum into the local medical programme. Issues flagged included perceived insufficient teaching time available to accommodate a formalised radiology curriculum and resistance from non-radiology clinicians who considered themselves the preferred teachers of medical imaging within their own area of expertise.[7]

The University of New South Wales has designed and introduced a medical imaging learning pathway for senior students consisting of a minimum of 8 h (non-sequential) of structured radiology and nuclear medicine lectures, with additional adaptive learning tutorials focusing on the clinical use and interpretation of chest X-rays and CT scans of the head, chest and abdomen. Radiologists and non-radiologist medical educators collaborated in development, aiming to build the key radiological knowledge required in practice from internship.[8] The first randomised trial of 99 junior medical students (years 1–4 of a 6-year programme) tested the adaptive learning tutorials against the 'Diagnostic Imaging Pathways' website, a well-established online medical imaging decision-making tool.[8,9] Greater learning benefit was

demonstrated in clinical level students, compared with their pre-clinical peers. Overall, the students required less time to complete the adaptive tutorials compared with the Diagnostic Imaging Pathways modules and there was greater perceived satisfaction with the adaptive tutorials.[8] A follow-up study in a smaller cohort of senior students (years 5–6) tested the adaptive tutorials against static articles from *Radiopaedia.org* and the Diagnostic Imaging Pathways website, finding significant improvement in post-test results for the brain imaging module, but no significant improvement for the chest imaging module.[10] Similarly, the students reacted favourably to the interface and inherent interactivity, recording high satisfaction and support for the programme. While results should be interpreted with care, the success of the purpose-built tutorials does appear to support the benefit of implementing carefully designed, 'fit-for-purpose' medical imaging learning tools.

Who are interpreting imaging studies?

The perceptions and realities of who currently is – and who should be – initially interpreting basic radiology studies are a contentious issue among the published literature. Multiple surveys of training and pre-vocational non-medical imaging clinicians have indicated that a majority of doctors are making clinical decisions based on their own interpretation of basic imaging investigations, which has in turn raised concern from radiologists that there is potential danger to patients in allowing junior medical staff to interpret and act on medical imaging findings without guidance.[3,4,7,11]

In the disciplines of surgery and emergency medicine especially, there is undoubtedly a need for image interpretation development so that non-radiologist clinicians possess the necessary skill to identify common and life-threatening pathologies at times when a radiologist may not be available for consultation in a timely fashion or at all.[3,4,12] Scenarios could include rural and remote practices, outside of business hours, immediately post-procedural (e.g. following placement of a new support line) or in situations where decision-making may be time critical. This does, however, need to be balanced against the ethical obligation to involve medical imaging specialists in the review of imaging studies and the obligation of non-imaging clinicians to ensure that this is occurring.

To explore this issue, a large survey of North American surgical faculty and residents was conducted and found that 73% of surgical faculty (of whom 48% were residents) interpreted radiological studies independently (i.e. without a radiologist) 'often or always', with a further 20% of faculty independently interpreting imaging 'sometimes'.[3]

This research comes at a time where after hours and remote reporting are relatively convenient and commonplace, which has meant that medical imaging services and non-medical imaging clinicians are more often removed from each other. Images can be requested and reviewed remotely, with reports accessible at the click of a button.[7] While perceived as a positive by medical students, surgeons and radiologists alike,[13] there are concerns that by moving more towards teleradiology radiologists will abdicate some traditional responsibilities (including post-imaging consultation with clinicians) and risk being increasingly viewed as a faceless commodity in the clinical landscape.[14]

In addition to this increasing distance and increasing workload, many radiology departments are becoming increasingly protocol driven, a trend which is eroding the long-held tradition of non-radiologist clinicians and junior doctors discussing scans with the radiologist. This had benefits not only in terms of patient care and non-medical imaging clinician education but also in fostering the development of interprofessional relationships and respect.[14,15] Junior doctors who traditionally had to physically interact with radiology trainees and consultants have less opportunity to do so, potentially sacrificing valuable informal learning opportunities.[4]

Stemming from this, it is hypothesised that some difficulties in collaborating for the purposes of education may arise from the presence of mismatched perceptions between educators and students (as well as between educators), where radiologists may be viewed as predominantly service providers, with little input into patient decision-making and management.[7]

Medical imaging knowledge and education for different non-radiologist clinician groups

There is near universal agreement in the literature regarding the importance of a basic working knowledge of medical imaging for junior doctors and non-radiology specialists, particularly for plain X-ray and basic CT investigations. It is also strongly encouraged that formalised medical imaging education should begin during medical school, with ongoing radiology education recognised as important for junior doctors, trainees, and specialists alike.[6,16] Even so, over the past 25 years, multiple studies have assessed the competency of junior doctors in interpreting plain radiographs and have consistently determined that general X-ray interpretation skills are suboptimal and argued that there is a need for improvement to the provision of medical imaging education beyond medical school.[17-22]

Pre-speciality training junior doctors

Independent surveys of recently graduated junior doctors in Australia,[6] Ireland[23] and the United Kingdom[24] found similar attitudes among participants towards the provision of diagnostic radiology education, as well as their preparedness for clinical practice. In both the Australian and Irish study, at least 98% of respondents indicated that

they felt they needed more radiology educational opportunities, with implementation of small group tutorial learning in junior doctors generating positive feedback and perceived clinical benefit among participants. In the UK cohort,[24] (which was surveyed ten years ago) almost 50% of junior doctors regularly turned to online resources to supplement their diagnostic imaging knowledge. While demonstrating a self-directed drive to learn, the junior doctors in this cohort rated guidance from radiologists themselves as most beneficial to their learning and ultimately improvement of patient care. Notably, the volume and quality of online resources in the area has vastly increased since 2010 when the research was published.

An observational study[25] of foundation doctors in the UK found the average hours dedicated to radiology education each year was 10.5 and 7.8 h for years 1 and 2, respectively, although this varied between sites. Hypothesised reasons included lack of time, inadequate facilities, unavailability of teaching staff, limited financial resources and absence of specific inclusion of radiology within the junior doctor curriculum.

A small UK-based study aimed at improving the awareness of the scope of nuclear medicine found measurable benefit from a single dedicated one hour lecture which introduced the junior doctors to the discipline.[26] Participants were able to retain knowledge of available nuclear medicine examinations and treatments beyond one month past the lecture, demonstrating the practice advantage of the implementation of even short-structured learning opportunities in this group.

When addressing the topic of radiation safety, including the risks and benefits of ordering particular diagnostic imaging investigations, Zhou and colleagues found a concerning lack of awareness in radiation safety topics among junior doctors and senior medical students.[27] For example, among the 331 surveyed, 26% believed that MRI and 11% believed that ultrasound emitted ionising radiation, which would likely play a role in considering the suitability of patients for examinations. The authors called for improved educational opportunities to address these knowledge gaps.

Surgical trainees and surgeons

Surveys of North American surgical residents have highlighted the desire for implementation of a formal radiology syllabus within the surgical training programme, ideally delivered by radiologists and surgeons together.[2,3,11,19] The current training environment has residents relying heavily on more senior surgical colleagues to provide medical imaging learning opportunities. This is despite the concerns raised by general surgery programme directors that patient care was too often compromised due to the lack of radiology knowledge among their trainees.[3,11]

While two large survey-based studies conducted by the same group found that surgical residents have reasonable accuracy of image interpretation for basic X-ray, CT and ultrasound [75%[2] and 74.2%[19]], both concluded that this could be improved with implementation of a formal medical imaging curriculum. As expected, surgical residents when compared to non-radiology trainees and other junior doctors were better able to interpret body CT and ultrasound but demonstrated comparable performance for plain X-rays, assessment of support lines and head CT. Note that assessment of 'accuracy' as a marker of competence can be a difficult metric, particularly if a high proportion of the studies used do not contain a clinically significant abnormality.

In contrast, a survey of programme directors for the United States otolaryngology residency programme found that 71% of programme directors had implemented a local radiology curriculum (despite the lack of national guidelines), with more than half of programmes making a dedicated radiology rotation available to their trainees.[28] Teaching methods included didactic sessions (presented collaboratively by radiologists and otolaryngologists), which combined lecture and case-based formats. Satisfaction with the amount and quality of content was high. Even acknowledging these successes, there were still calls by authors for formalised provision for medical imaging and establishment of a nation-wide curriculum to address heterogeneity of educational opportunities and topics covered across sites and further promote multidisciplinary cooperation.

Physician trainees and physicians

In the United States, competency in chest X-ray interpretation across physician (internal medicine) trainees, medical students and radiologist trainees was compared by Eisen *et al*.,[20] finding significant differences between the accuracy and confidence of these groups. Unsurprisingly, accuracy increased with years of clinical experience with students found least accurate, followed by interns, internal medicine residents and internal medicine fellows. When compared with radiology residents, even senior physician trainees were found to be significantly less accurate when interpreting normal and abnormal chest X-rays. There was an expected correlation between increasing seniority, increasing confidence and diagnostic accuracy (concordant with results from other groups[22]); however, a large proportion still felt that they did not have sufficient medical imaging training available to them.[20]

Similar results were found when general surgical trainees were compared with physician/ internal medicine trainees and radiology residents regarding the interpretation of X-ray, basic CT and ultrasound.[19] Across all modalities, physician trainees returned 67.9% accuracy, surgical trainees 74.2% and radiology trainees 83% (with the difference significant across the groups). Poorest modality performance was encountered in plain films and ultrasound for both groups (physicians 61.4% and 61% accuracy, respectively, and surgeons 64.1% and 68.2%).

These results are expected, given that physicians (like surgeons, critical care specialists and general practitioners) are not trained to be medical imaging specialists. The problem is that in practice, these clinicians are often shouldering the responsibility of interpreting their patient's imaging (by choice or circumstance), therefore mandating a high level of competence.[19,20]

Even the provision of short educational programmes has measurable benefit to physicians in terms of both their interpretation of chest radiographs[29] and knowledge of radiation safety.[30] In the study by Ngatu and colleagues, a two-hour targeted education for respiratory physicians improved image interpretation of chest X-ray studies for investigation of pneumoconiosis; however, it was conceded that a longer dedicated workshop would be the ideal learning scenario.[29] The latter study recognised deficits within radiation safety knowledge and argued that the demonstrated increased awareness of the risks and benefits of radiation would have a positive impact on patient care.[30]

Emergency medicine trainees and specialists

Surveys of US emergency medicine training residents revealed similar dissatisfaction regarding the lack of a formal radiology curriculum and training opportunities for junior doctors.[4] This cohort valued informal on shift teaching as a primary method of learning, supervised by faculty teachers without official interpretation of studies by a radiologist, recognising the inevitability of needing to interpret imaging without the support and expertise of a trained radiologist. 80% of surveyed doctors interpreted plain radiographs at least once per shift, with higher confidence in interpreting radiological examinations correlated with greater exposure to on-the-job experience without an available radiologist. Even so, there was a call for on-the-job experience to be supported by formal lectures/learning opportunities.

There has been demonstrated benefit in approaching emergency department medical imaging education in collaboration between the emergency and medical imaging departments in a real-world, case-based setting.[5] A system for review/interpretation of radiographs was implemented both in and out of hours, with a monthly discrepancy meeting and teaching library created for ongoing education, decreasing the false negative rate for interpretation of basic imaging studies (3% to 0.3%) extrapolating to a decline in potential adverse events from 19/1000 to 3/1000.

Radiation oncology

Highlighting the importance of medical imaging to this cohort of trainees is especially relevant due to the role of CT in treatment planning and delivery for radiation oncology patients. A US survey of radiation oncology trainees found that they rated knowledge of diagnostic radiology moderately or extremely important, with a majority also unsatisfied with the radiology training provided by their programme expressing the desire for didactic lecture content to consolidate on-the-job learning, for example from multidisciplinary meetings.[31] In the Australian radiation oncology curriculum, diagnostic imaging learning points are integrated throughout the syllabus – including within the context of basic physics knowledge and integrated clinical knowledge for specific conditions.[32] The curriculum document does not stipulate about how and by whom this content will be delivered.

Factors influencing confidence among non-radiologist clinicians

As would be expected, the degree of confidence, comfort and accuracy of interpreting medical imaging studies among non-radiologist increases with experience.[20] In addition, for emergency and surgical trainees who worked at a hospital site without access to radiology support for all or a significant part of their clinical experience, clinician confidence was increased.[3,4] This is most likely due to the greater exposure to real-time reading during shifts, as well as greater responsibility taken for personal clinical judgments.

Although imaging competency is essential to the practice of radiation oncology, a North American study found that a majority of graduating fellows only feel 'somewhat confident' in their imaging interpretation skills.[31]

Promoting education opportunities which are 'fit-for-purpose'

When Murray[15] reflected on the medical imaging teaching provided to foundation doctors by radiologists in the United Kingdom, she commented that 'few of us have the time to stop and wonder 'what is the aim of this education process?' or 'what sort of doctors are we trying to produce?''. She recognised the role that radiologists must take upon themselves to educate junior colleagues in a manner which is relevant, and which ultimately serves to build others as stronger medical professionals who are better equipped to use medical imaging to optimise patient outcomes. To achieve this in her own practice, she reported changing her approach to teaching to move away from purely reviewing static images to discussing the role of radiology in patient management including indications for specific tests, benefits and limitations, weighing up safety concerns, counselling patients and managing unexpected or inconclusive results.

Sensibly, surgeons are advocating that should a formalised curriculum emerge, it should look towards identifying key gaps in essential knowledge and providing the residents with relevant knowledge (i.e. spending time and resources on information which is high yield in practice), and aim for efficient content delivery around the constraints of work.[2]

The role of online medical imaging resources

The importance of the implementation of interactive medical imaging educational tools for junior doctors has been recognised for over ten years,[24] during which time the availability of online medical imaging resources has vastly increased. Interactive medical imaging learning tools are becoming increasingly (and successfully) implemented;[8,10,33-37] however, peer-reviewed literature in the junior doctor setting is presently limited.

Radiopaedia.org has provided global access to a wiki-based collaborative radiology learning resource, which contains an open case library of nearing 40 000 cases and over 14 000 articles which are curated by a team of medical imaging professionals.[38,39] While the educational resources provided by *Radiopaedia.org* have been formally evaluated in the medical student setting, it has not been formally evaluated in the context of junior doctor education, although praised anecdotally as an excellent resource in this setting.[7]

When evaluating *Radiopaedia.org's* 'Playlist Feature' (providing interactive cases, with scrollable cross-sectional imaging and cross-linked with written information and multiple-choice questions) against traditional static reading materials for teaching medical students paediatric radiology, it was found that those who used the playlists demonstrated improved understanding and application of the ACR (American College of Radiology) appropriateness criteria and identification of the 'silhouette sign' on chest x-rays.[40] The value of the 'Playlist Feature' has also been praised as a valuable tool for educating radiologists and nuclear medicine physicians.[41,42] When comparing purpose-built medical imaging adaptive tutorials for medical students against *Radiopaedia.org* articles, 'adaptive tutorials' were found to be superior; however, it could be argued the greater success for the *Radiopaedia.org* would have been found should a purpose-built playlist have been the metric of comparison.[10]

The Western Australian developed 'Diagnostic Imaging Pathways' have also been shown to be a valuable online resource for non-radiology clinicians, especially in terms of ordering of investigations, understanding imaging triage and supporting clinical decision-making.[43] Again, when compared to the use of 'adaptive tutorials' for medical student education purposes, the 'Diagnostic Imaging Pathways' was less effective as a primary learning tool.[10]

DetectED-X is a Sydney-based team who have created a cloud-based platform for assessment and enhancement of image interpretation performance.[44] The group initially developed 'BREAST Test Sets' for use in improving mammogram breast cancer detection by radiologists and radiology trainees.[45] In 2020, the platform expanded to find a role in chest imaging during the COVID-19 pandemic (CovED), which provided a free, cloud-based, fully online learning tool to all clinicians (not just radiologists) across the globe, containing a set of Lung Computed Tomography scans to assist in the recognition of imaging findings associated with COVID-19. Both BREAST and CovED platforms provide readers with immediate and personalised feedback. While data from the 2020 CovED project are yet to be published, evaluations of the BREAST Test Sets demonstrated improvement in lesion detection among radiologists and trainees who completed multiple Test Sets suggesting a positive impact on the diagnostic efficacy in those radiologists/trainees who used the tool.[45]

The rise of online learning has also presented greater emerging opportunities for junior doctors to pursue formal medical imaging education within a tertiary learning environment. The Professional Medical Education Unit of the Sydney University Medical School has implemented dedicated medical imaging units of study within the Master of Surgery and Master of Medicine programmes.[46,47] The unit within the Master of Surgery programme has been taught solely online since 2016, with content delivered by radiology and non-radiology experts. The Master of Medicine unit was launched online in 2019, built in collaboration between non-radiology specialists and educators, and the majority delivered by radiologists. Both programmes employ a mixture of recorded lectures, discussion boards and interactive quizzes to teach content. Programmes are well subscribed, mostly by doctors who are in their first few postgraduate years of practice.

Collaborating across disciplines

When considering interprofessional collaboration, Van Deven and Hibbert[48] argued that it was necessary for medical imaging professionals to break down 'professional silos' to work effectively together and open lines of professional dialogue. This included addressing preconception that specialties do not know enough about each other to collaborate. Their argument of building awareness among non-imaging colleagues has been echoed in the work of others,[26,49] who have highlighted that a lack of medical imaging education leads to a lack of awareness of the potential services available to address certain clinical questions (ultimately impacting optimal patient care), as well as having implications for the allocation of health resources. The quality of education also stands to be improved with joint efforts across specialties.[7,15] There is currently limited evidence for the value of the participation of radiologists in formal specialty training in non-medical imaging disciplines; however, this could be an area for further examination in the future.

Considering the role of artificial intelligence (AI)

As AI begins to transition from the research sphere into clinical practice, there will be the capacity (and need) for adaptation of these new technologies into the education space from medical school onwards.[50] This would potentially involve not only using AI-based teaching tools to

teach medical imaging concepts and diagnoses or tailoring educational solutions for the individual but also broadly educating clinicians as to the role that AI can play within clinical decision-making and practice. Currently, there is little research evaluating AI in the space of educating non-imaging specialists; however, surveys of medical students and surgeons have revealed that the concept of AI is met with a degree of uncertainty within these groups. Within a surveyed cohort of medical students, surgeons and radiologists, there was broad agreement that AI should be progressively integrated into the practice of diagnostic radiology; however, interestingly, radiologists were more supportive of this development than their non-medical imaging counterparts.[13]

Limitations of the literature

Review of the literature surrounding the provision of medical imaging education to non-radiologist clinicians has revealed comparatively few studies compared with those aimed at medical students, although this would be expected given the relative captive audience of a medical school cohort. Nine of 21 cohort studies drew from sample sizes <100, with 3 drawing from less than 50 participants, which may have an impact on the reliability of the data presented.

The greatest proportion of the higher-powered studies arise from North American populations, meaning that local data on medical imaging education for non-radiologist clinicians post medical school are limited to a few studies which primarily survey attitudes and access. One of the concerns with surveying attitudes towards medical imaging education is that metrics such as 'satisfaction' and 'confidence' may not accurately reflect the imaging aptitude of those surveyed in all cases. This said, at least one study considering this relationship found a positive correlation between accuracy and doctor confidence when interpreting imaging studies.[20,22]

A further issue when evaluating medical imaging knowledge and application arises with using predetermined cases which have a 'correct answer' as the endpoint. While common and life-threatening diagnoses will often have a characteristic imaging appearance, such clear-cut scenarios occur relatively infrequently in clinical practice. Diagnostic uncertainties and non-specific findings commonly muddy the waters of interpretation in many (even normal) cases. In addition, the test sets would most likely have a greater proportion of cases with a clinically significant abnormality when compared to the realities of practice.

Conclusions

Overall, there are relatively few current and high-quality studies, which examine the provision of medical imaging education to junior doctors and non-radiologist clinicians. Clearly, this is an area of great importance, given the near ubiquitous use of imaging throughout all fields of medicine, and the increasing need for real-time interpretation by non-specialists.

In the studies which have been published, two common themes emerge. Firstly, there is a demand for more medical imaging education at all levels from medical students through to non-radiologist specialists, and a recognition that radiologists need to play a leading role in the design and provision of this education. Second, there is good evidence that even a small amount of structured medical imaging teaching can meaningfully improve performance. These improvements are seen even in the setting of unsupervised online learning environments.

Specialists and junior doctors are professionally obliged to look for opportunities to improve their medical imaging interpretation skills, regardless of their level of training and specialty, as it has the potential to improve the quality of their patient care. Non-radiologist clinicians consistently express a desire for greater confidence and knowledge regarding their interactions with medical imaging. Undoubtedly, on the job experience and development of image interpretation skills is important to the growth of a doctor in any specialty. Placing the responsibility of teaching radiology onto non-radiologist clinicians may ensure relevance but runs the risk of perpetuating misinformation and altered perceptions of the role of medical imaging.

Among educators, the prevailing belief common across countries and learning environments is that quality of medical imaging education, and by extension patient care, would be greatly benefitted by the inclusion of formal radiology learning opportunities within medical training curricula. When this occurs, it is important that the education provided is relevant and high yield within the given clinical scenario; a programme which is 'fit-for-purpose' is likely best borne out of collaboration between specialists 'in' and 'outside' of radiology.

As the literature demonstrates the majority of post-medical school imaging education for non-radiology junior doctors is delivered in an informal setting (often by more senior clinicians within their own specialty), there is a need to ensure adequate knowledge and expertise among these educators. Collaboration across imaging and non-imaging specialties is essential to provide relevant and high-yield educational opportunities which fit the learning goals and clinical scope of education in these 'on-the-job' clinical settings. This should ideally include practical imaging interpretation skills beyond spot diagnoses and recognition of classic scan appearances, which may well be a departure from more classical medical imaging lectures.

While not extensively tested in the junior doctor or clinical setting outside of the realm of the radiology department, there is also evidence accumulating for the benefit of utilising online learning resources for medical imaging education, especially when they are interactive and relevant. The flexibility and accessibility offered by online learning has bolstered significant growth in resources in recent times, which will likely continue to cement itself in the educational landscape. The widespread introduction

and progressive development of interactive e-learning environments would stand to enhance practical interpretation skills, supported by the growing volume of literature evaluating specific online education and decision-making tools with broadly favourable results.

Above all, it is important to keep in mind that our goal as imaging educators is to improve patient care through better use of imaging data, not to train non-radiologists to do the job of medical imaging specialists. Our junior and senior colleagues outside of imaging should possess the basic knowledge and understanding to order and interpret images so that patient care is optimised, including the ability to make safe real time decisions, identify common and life-threatening diagnoses, and know when to seek out the guidance of the expert radiologist. As educators, we should be aiming to empower our colleagues to interact with the physical images and radiologists alike and do so without fear of being replaced or superseded. In doing so, we stand to continue to build a profile for our profession based on value and mutual respect, which stands to bring greater benefit to our patients.

Ethics & Integrity

Dr Sally Ayesa, A/Prof Annette Katelaris & Prof Stuart Grieve are associated with the University of Sydney School of Professional Medical Education, within the Faculty Medicine & Health. Dr Sally Ayesa is associated with Radiopaedia.org. Prof Patrick Brennan & Prof Stuart Grieve are associated with DetectedX. Prof Stuart Grieve acknowledges the support of the Parker-Hughes Bequest, the New South Wales Office of Health and Medical Research and the Frecker Family. No further grants or funding to disclose.

Data availability

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Methodology and results from preliminary literature survey.