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Title:

Image Interpretation by radiographers in brain, spine and knee MRI examinations: Findings from an accredited postgraduate module

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Abstract

Introduction:

The aim of the study was to evaluate the performance of radiographers in image interpretation of magnetic resonance imaging (MRI) brain, spine and knee examinations following a nine-month work based postgraduate MRI module.

Methods:

Twenty-seven participants each submitted 60 image commentaries taken from prospective clinical workloads. The image interpretations (*n*=1,620) comprised brain, spine, and knee MRI examinations. Prevalence of abnormal examinations approximated 53% (brain), 74% (spine), and 73% (knee), and included acute and chronic pathology, normal variants and incidental findings. Each image interpretation was graded against reference standard consultant radiologist definitive report.

Results: The radiographer's performance on brain image interpretations demonstrated mean accuracy at 86.7% (95% CI 83.4-89.3) with sensitivity and specificity of 84% (95% CI 80.9-86.4) and 89.7% (95% CI 86.2-92.6) respectively. For spinal interpretations the mean accuracy was 86.4% (95% CI 83.4-89.0), sensitivity was 90.2% (95% CI 88.2-92), mean specificity was 75.3% (95% CI 69.4-80.4). The mean results for knee interpretation accuracy were 80.9% (95% CI 77.3-84.1), sensitivity was 83.3% (95% CI 80.8-85.5), with 74.3% specificity (95% CI 67.4-80.4).

Conclusions: The radiographer's demonstrated skills in brain, spine and knee MRI examination image interpretation. These skills are not to replace radiologist reporting but to meet regulating body standards of proficiency, and to assist decision making in communicating unexpected serious findings, and /or extend scan range and sequences. Further research is required to investigate the impact of these skills on adjusting scan protocols or flagging urgent findings in clinical practice.

Introduction

Within the United Kingdom (UK) the rationale for image interpretation training in radiography education has been to provide the knowledge, skills and experience to fulfil Health and Care Professions Council (HCPC) requirements. These are set out within the Standards of Proficiency[1] for each radiographer to understand the imaging appearances of healthy human anatomy and disease appearances relevant to their imaging modality, with an emphasis on the ability to competently assess and appraise image data, and record appropriate information to assist in formulating plans if further action is required. The HCPC Standards of education and training[2] require practice educators to tailor their programmes to the clinical requirements of the profession and support practice-based and campus learning relevant to the professional needs of the occupation. Postgraduate education in the UK is approved and accredited by the College of Radiographers (CoR)[3] to maintain standards of education that support and encourage the development of educational opportunities aligned to clinical practice and career framework guidance.[4] The CoR preliminary clinical evaluation (PCE) policy[5], promotes the view that image interpretation is a core part of the radiographer's scope of practice. The guidance[5] stipulates that opportunity is only limited by the range of radiographer practice. As yet PCE has to our knowledge not been expanded in practice from plain film radiographs[6,7,8] into cross-sectional modalities such as magnetic resonance imaging (MRI), although it may only be a matter of time and clinical demand.[9]

Within the UK there have been specific resource challenges, evidenced by the Royal College of Radiologists (RCR) of historical[10] and current[11] radiologist workforce shortages that have impacted on-site MRI scanning support. Recent estimates state the radiologist workforce to be one of the lowest per population in the European Union (7.5 per 100,000 population)[11] contributing to an increase in delays of more than 30 days in National Healthcare Service (NHS) MRI reporting. With 4,268 scans outstanding in 2015,[12] 7,770 scans in 2016,[13] to 97% of UK radiology departments failing to meet reporting targets in 2017.[11] In this instance, MRI image review post-acquisition by radiographers has the potential to flag urgent findings for rapid reporting to medical and non-medical reporters to reduce patient treatment and management delays.

Drivers for service improvement in MRI include Department of Health (DoH) priorities[14,15] to improve the efficiency of NHS diagnostic services against the substantial pressure of increasing referrals. Within the NHS there was an increase of 125% in MRI examinations in 2004-2011[10], and more recently a 76% rise between 2012-16.[11] Combining these figures with data from the Organisation of Economic Cooperation and Development (OECD)[16] that reported the UK has only 6.1 MRI scanners per million population (one of the lowest rates in Europe), yet capacity is at 56.3 scans per 1,000 population (above the OECD average)[16] reflecting high demand and utilisation rates in the NHS. In assessing the current system, the Care Quality Commission[14] and NHS England[17] have advised that to carry on delivering safe and sustainable levels of healthcare delivery the NHS will be required to think beyond the traditional boundaries of systems, service and clinical practice to support local improvements in quality of care and patient outcomes.

This study aims to analyse the results of summative image interpretation assessments of brain, spine and knee MRI examinations by the first five cohorts of diagnostic radiographers (*n*=27) on an accredited[3] part-time work based 20 credit Level 7 postgraduate MRI module at Canterbury Christ Church University.

The module curriculum, learning, teaching and assessments were developed in partnership with local NHS stakeholders and consultant radiologists. Each radiographer had a minimum of six mentored and supervised (by senior radiographers) clinical sessions a week. The learning outcomes covered a mix of competency-based tasks in scanning and interpretation of standard brain, spine (cervical, thoracic, lumbar, and in combination) and knee MRI examinations. The anatomical areas were chosen in consultation with local stakeholder departments as three of the most common routine examinations performed locally. The knowledge and skills taught incorporated professional judgement and decision making in referral criteria, understanding the range and function of imaging equipment, anatomy, physiology and pathology, with Radiologist led tutorials on MRI search strategies and image interpretation commentary structure. The module assessments include a case study, reflective audit essay, and portfolio of a minimum of 120 image interpretation commentaries (60 formative, and 60 marked summative commentaries certified by departmental radiologists and mentors).

The image interpretation competencies in the postgraduate module aim to assist MRI radiographers working in mobile and static scanning departments that may not have on-site radiologist support to review imaging at the time of acquisition (either in out of hours imaging, seven day working shifts or remote sites). The application of abnormality detection skills have the potential to help to make informed and reasoned judgements to manage patients effectively, to assist in flagging unexpected findings [18-20] and to aid and support decision making in scan protocol/sequence adjustments to cover unanticipated peripheral abnormalities.

Method

This study received institutional ethics approval (16/H&W/CL188). The caseload mix consisted of prospective imaging worklists to reduce prevalence bias, and accurately reflect clinical practice.[21,22] Each participant submitted 60 mixed summative cases for assessment, the range of referral sources included acute and chronic referrals from in and outpatient pathways, general practitioner and trauma.

The radiographers had access to the patient's pre-examination clinical information (gender, age, clinical history and symptoms).[23-26] The image interpretation commentaries were completed independently, and prior to the radiologist report, which was likewise blinded to the student's commentaries during the reporting of the examinations.[21,27,28] Each image interpretation was completed at the time of acquisition using Digital Imaging and Communications in Medicine (DICOM) compliant monitors.[27,28] Each of the radiographers completed a free text commentary to record if the case was normal or abnormal. In abnormal judgements, the radiographers provided a written interpretation to identify abnormalities using descriptive terminology including anatomy, location and characteristics, as specified by CoR guidance[5], also if the pathology had not been entirely imaged in the scan length, the field of view, or if additional sequences/protocols are required. Normal cases incorporated normal variants, abnormal cases included acute trauma, chronic neurological and musculoskeletal conditions, degeneration, and lesions (Table 1).

The definitive radiological report was provided by a team of consultant neuroradiologists for the brain and spine, and consultant musculoskeletal radiologists for the spine and knees.[27,28] Spine examinations were split between the two radiologist sub-specialities dependent upon the clinical history, symptoms and questions. The RCR[29] define radiological reports as a clinical opinion from the interpretation of imaging, and as such two or more radiological opinions of the same case has been evidenced to show variation.[30] Single expert reference standards are prone to discrepancies as evidenced by inter-observer variation,[31,32] potential opinion bias was reduced by applying a panel of radiologists (minimum of two per case).[21,33]

Evaluation of each image interpretation commentary and definitive radiology report was assessed in clinical practice (student's department) by radiologists. With second marking against the definitive radiology report by a panel of three academic staff members (qualified in MRI reporting, and with senior MRI radiographer experience) on campus.[21,28] If the interpretation was correctly recorded as normal/abnormal, they were allocated a true negative (TN) or true positive (TP) whole mark. If the case was incorrectly assessed, it was allocated a false negative (FN), or false positive (FP) score.[34,35] Fractionated scoring for multiple pathological conditions was applied which allowed recognition if partial elements (correct pathological conditions) were noted and not penalised unjustly where multiple conditions were present, and not all are identified. For example, applying two equally important lesions in an anatomical area (brain, spine or knee), and only one is identified thus the marking would reflect 0.5 TP and 0.5 FN (if four lesions were present 0.25 fractions would be applied per abnormality).[27] Statistical analysis (IBM Corp. 2016. IBM SPSS Statistics, Version 24.0.0.2, New York, USA) calculated accuracy, sensitivity, and specificity,[28,35] with 95% Confidence Intervals (95% CI)[21,28,36] calculated using Wilsons method.

Results

The study sample included 27 radiographers, the demographics of the group were 12 males, 16 females, mean age 37 (range 24-52) years, and with a mean 10 (range 2-28) years of MRI experience.[27] Twenty-seven MRI departments were represented and included 18 urban hospitals, 4 rural hospitals and 5 specialist inner-city hospitals. The number of cases per anatomical category and abnormality prevalence[28] are displayed in Table 1 and 2; all cases were imaged using 1.5 Tesla MRI scanners.

The results of image interpretations of MRI brain examinations (*n*=532) demonstrated mean accuracy at 86.7% (95% CI 83.4-89.3) with sensitivity and specificity of 84% (95% CI 80.9-86.4) and 89.7% (95% CI 86.2-92.6; Table 3a) respectively. For spinal MRI image interpretations (*n*=592) the mean accuracy was 86.4% (95% CI 83.4-89.0), sensitivity was 90.2% (95% CI 88.2-92), specificity was 75.3% (95% CI 69.4-80.4; Table 3b). The MRI knee image interpretation (*n*=496) accuracy was 80.9% (95% CI 77.3-84.1), sensitivity was 83.3% (95% CI 80.8-85.5), with 74.3% specificity (95% CI 67.4-80.4; table 3c).

Individual cohort group scores showed variation in results due to the diversity of applying prospective worklist cases that produce random and inconsistent prevalence of abnormalities and numbers of cases attended and interpreted. This variation of factors can affect individual radiographer results, thus the data has been pooled to display a total. Of the discrepancies found in the data and results of the image interpretations (*n*=1,620), minor disagreement (no clinical significance regarding a change of treatment or management plan) was found in some brain, spine and knee cases as reported above in the results. These included absence vs presence of previous small chronic lacunar lesions occurring in the basal ganglia, away from peripheral acute large infarctions on stroke and dementia brain scans, and discrepancies on minor degenerative appearances in brain imaging. In cases of the spine, minor disagreement was noted in examples of the amount of osteophyte presence in degenerative spondylosis cases, and presence of Schmorl's nodes. Likewise, knee cases had minor disagreement on descriptions of degeneration of cruciate ligaments and iliotibial band syndrome. No major disagreements (the potential of significant change to patient treatment plans or patient harm) such as missed tumour, fracture, or infection, was evidenced. Although the task requirements in this study were not to produce a definitive clinical report but image interpretation commentaries to aid image acquisition adjustments if necessary or immediate referral for urgent reporting.

Discussion

There is a paucity of published MRI image interpretation studies by radiographer's to allow direct comparison to the results. There are published papers on clinical reporting in MRI by radiographers[31,35,37] on retrospective reporting of MRI cases of internal auditory meati (IAM) in an academic setting,[37] and prospective and retrospective reporting of lumbar spine and knee MRI examinations in an academic[35,37] and clinical environment.[31] However, the task of clinical reporting is distinctly different in role and training from image interpretation at the time of acquisition to allow direct comparison. Additionally, study case sample sizes reported were different,[31,35,37] and in some cases the participant numbers were higher[35], and although the assessment criteria[31,35] were similar, these factors will affect the results generated for comparison.

Image interpretation of MRI examinations is a complex task due to the large number of images per sequences obtained and can be prone to error due in part to the latent complexity and intricacy of the anatomy displayed. Studies by Brady[30] and Kim and Mansfield[38] provide excellent root cause analysis of potential further reasoning and contributing factors as to why errors in MRI image interpretation and reporting occur in the clinical environment, which the RCR[33] acknowledge and recommended routine audit to monitor discrepancy rates in MRI image interpretation to safeguard practice. This is similar to the CoR[5] and HCPC[1] guidance for radiographers to audit their work for quality improvement and continuing professional development.

Analysis of the written image interpretation commentaries highlighted the application of terminology applied by the radiographers. Cosson and Dash[39] recommend the correct and exact use of anatomical terms are essential in image interpretation commentaries to reduce misunderstandings. It was affirmed within the analysis that the commentaries differed in style and structure between the radiographer's written image interpretation prose, and the Radiologists structured reference standard reports used as the marking criteria. The radiographer's responses, however, contained concise lexicon and detail on the site, location, anatomy and appearance of abnormalities to assist initial clinical decision making in scanning or urgent radiologist referral.

Within the FN errors analysed in the brain, spine and knee cases were examples of failing to discriminate a subtle lesion from normal anatomical structures where multiple examples of the condition were present, and or missing secondary lesions when adjacent to substantial primary abnormalities. Although no direct change in patient management would have occurred in these cases of multiple and complex pathologies. This failure as classified by Berlin[40] and Lee et al[41] concerns the detection of one radiologic abnormality affecting the identification of further subtle findings from normal surrounding anatomy can be termed satisfaction of search errors. Although the amount of FN cases were low, it affected the overall score of the radiographers and may reflect the novice learning. The FN marks allocated in brain interpretations were noted to centred on missed lacunar infarcts (in the case of multiple small lacunars) and subtle changes to the white matter around the ventricles which was noted to be subjective in detail. Studies by Kapeller at al[42] and Wahlund et al[43] reason that the use of visual rating scales may improve reliability in this interpretation task. Spinal FN scores reflected missed Schmorl's nodes, osteophyte formation and small haemangiomas (in cases of multiple presences). Specific FN errors of the cervical spine included minor ligamentous injuries, missed annular tears, disc protrusion in relation to the exit foramina (in cases of multiple presences), and small Syrinx (in a case of multiple conditions). Thoracic and lumbar spine FNs included Scheuermann's disease, focused areas of vertebral body spondylotic defects, facet joint hypertrophy and root compression (in cases of multiple presences). These reflected the complexities reported by Van Rijn et al[44] and Lurie et al[45] of difficult image interpretation appearances in the degenerative spine.

Within the knee analysis of performance, FN scoring concentrated on the misinterpretation of degeneration of cruciate ligaments as ruptures, missed meniscal tears, and iliotibial band syndrome (in cases of multiple conditions). Krampla et al[32] have observed that inexperienced interpretation levels may contribute to FN meniscal tears decisions. Further FN errors were found in visualising anterior cruciate ligament injuries on MRI by the radiographers, and in part, this was down to MRI visualising the anatomy clearly for diagnosis. The difficulties of which have been identified in a study by Devitt et al[46] who considered in this situation whether an MRI is appropriate due to the inherent difficulties of the anatomic shape and the imaging plane.

Normal anatomical variants were noted within the cases as atypical findings as these presentations in the imaging exhibited no bearing on the clinical significance or patient outcome. Normal variants simulating pathology in the brain cases included asymptomatic and minor of Chiari Malformation 1 congenital anatomy displacement without brainstem compression and resulted in FP scoring. Interpretations of the spine recorded FP scoring in cases of incorrectly stated impingement and compression of sacral nerve roots, overcalling ligamentum flavum hypertrophy, minor spinal stenosis, and a case of scar tissue mimicking pathological change. Within knee FP commentaries, variant anomalies included cases of a medial plica, and discord lateral meniscus all of which can imitate injuries to the inexperienced. Further, abnormal image signals which affected the students' performance were initiated by technical image acquisition errors. These were noted specifically in a small sample of FP errors related to Image artefacts. A case of truncation artefacts was presented, likewise, Gibb's artefacts mimicking syringomyelia in the spinal cord, magic angle effects in knees[47] imitating a patellar tendon tear, and patient movement affecting anatomical detail and interpretation.

Limitations

An acknowledgement of the limitations in this image interpretation study includes the small participant sample size and caseload sample which limit the research findings. As such, further study is required to validate a large sample size of participants in MRI image interpretation. Likewise, further research is warranted to audit the application and impact of these skills to flag urgent findings to medical and non-medical reporters in a clinical environment (this task was to produce an image interpretation commentary, not a definitive clinical report and as such the postgraduate training reflected this). Furthermore, future research would benefit reviewing the influence of image interpretation in scan protocol adjustments to cover the field of view when unexpected findings are found to assess its clinical application.

Conclusion

In this study, we have presented the results of image interpretation commentaries by radiographers assessing brain, spine, and knee MRI examinations. In acknowledging the novice image interpretation ability and limitations, further review after a period of exposure to a wider range of cases and conditions is recommended. It is recognised this is an opportune time to develop these skills given the current issues and challenges facing MRI service delivery within the UK health service. The postgraduate learning and continuous professional development within this study align with HCPC Standards of Proficiency[1] relevant to the radiographer's scope of practice and modality to gain knowledge and skills to practice safely and effectively.

Word count 2880

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Conflict of interest statement

No conflict of interest, financial or otherwise, to declare.

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Table 1. Abnormal case conditions

Brain	Spine	Knee
Degeneration	**Trauma**	**Trauma**
Small vessel disease	Ligamentous injury	Cruciate ligament injury
Atrophy	Annual tears	Meniscal tear
Neurological	Scar tissue	iliotibial band syndrome
Infarction	Fracture	Effusion
Multiple sclerosis	**Degeneration**	Hoffas fat pad
Hydrocephalus	Spondylolysis	Fracture
Lacunar	Disc protrusions	**Degeneration**
Lesion	Schmorl's nodes	Ligament degeneration
Metastasis	Osteophytes	Popliteal cyst
Pineal gland cyst	Scheuermann's disease	Osteochondral defect
Arachnoid cyst	Facet joint hypertrophy	Avascular necrosis
Meningioma	Nerve root compression	Mucoid cyst
Acoustic schwannoma	Ligamentum flavum hypertrophy	Cartilage loss
Normal Variant	Spinal stenosis	**Lesion**
Chiari malformation	Scoliosis	Lymphangiomas
Mega cisterna magna	**Neurological**	**Normal Variant**
	Cauda equina	Medial plica
	Syringomyelia	Discord lateral meniscus
	Lesions	Patella alta
	Haemangioma	
	Metastasis	
	Normal Variants	
	Os odontoideum	

Table 2. Abnormality prevalence ratio (abnormal cases/total cases).

	Brain	Spine	Knee	All cases
Total abnormality prevalence	283/532 (53.1%)	439/592 (74.1%)	364/496 (73.3%)	1086/1620 (67%)
Mean	10.48	16.25	40.22	40.22
Standard deviation	4.41	5.21	6.97	6.97
Minimum	1.00	7.00	26.00	26.00
Maximum	18.00	29.00	50.00	50.00

Table 3a. Cohort MRI Brain image interpretation results.

	Data					Results					
Radiographers	**Cases**	**TP**	**TN**	**FP**	**FN**	**Accuracy**	**95% CI**	**Sensitivity**	**95% CI**	**Specificity**	**95% CI**
2008/09 (*n*=7)	*n*=146	76	53	7	10	88.4	81.4-93	88.4	82.5-92.3	88.3	79.9-94
2010/11 (*n*=5)	*n*=102	28	62.5	7.5	4	88.7	80.3-93.7	87.5	74-95.4	89.3	93.1-92.9
2012/13 (*n*=2)	*n*=40	16	17	1	6	82.5	66-87.2	72.7	57.8-77	94.4	76.1-99.7
2014/15 (*n*=6)	*n*=105	54	37	4	10	86.7	78-91.6	84.4	77.3-88.4	90.2	79.2-96.5
2016/17 (*n*=7)	*n*=139	64	53.5	6	15.5	84.5	77.1-89.3	80.5	74-84.7	89.9	81.2-95.5
Total (*n*=27)	*n*=532	238	223	25.5	45.5	86.7	83.4-89.3	84	80.9-86.4	89.7	86.2-92.6

Table 3b. Cohort MRI spine image interpretation results

	Data					Results					
Radiographers	**Cases**	**TP**	**TN**	**FP**	**FN**	**Accuracy**	**95% CI**	**Sensitivity**	**95% CI**	**Specificity**	**95% CI**
2008/09 (*n*=7)	*n*=145	99	25	14	7	85.5	78.7-90.3	93.4	88.8-96.7	64.1	51.5-73.1
2010/11 (*n*=5)	*n*=121	94.5	18.5	5	3	93.4	87-96.9	96.9	93-99.1	78.7	62.2-87.6
2012/13 (*n*=2)	*n*=40	20	13.5	2	4.5	83.8	67-91.8	81.6	68-88.2	87.1	65.5-97.5
2014/15 (*n*=6)	*n*=136	91.5	31.5	6	7	83.8	67-91.8	81.6	68-88.2	87.1	65.5-97.5
2016/17 (*n*=7)	*n*=150	92	26	10.5	21.5	78.7	71.5-84.4	81.1	76.3-84.9	71.2	56.4-83.1
Total (n=27)	*n=592*	397	114.5	37.5	43	86.4	83.4-89	90.2	88.2-92	75.3	69.4-80.4

Table 3c. Cohort MRI knee image interpretation results

	Data					Results					
Radiographers	**Cases**	**TP**	**TN**	**FP**	**FN**	**Accuracy**	**95% CI**	**Sensitivity**	**95% CI**	**Specificity**	**95% CI**
2008/09 (*n*=7)	*n*=129	85	26	9	9	86	78.5-91.6	90.4	85.3-94.2	74.3	60.5-84.4
2010/11 (*n*=5)	*n*=77	45	22.5	6	3.5	87.7	77.2-93.7	92.8	84.5-97.5	78.9	64.9-87.1
2012/13 (*n*=2)	*n*=40	25	3	1	11	70	59.6-74.7	69.4	63.7-72.1	75.0	22.9-98.7
2014/15 (*n*=6)	*n*=119	75	18	7	19	78.2	70.2-84.1	79.8	74.8-83.6	72.0	53.2-86.2
2016/17 (*n*=7)	*n*=131	74.5	27.5	10.5	18.5	77.9	69.7-84.3	80.1	74.4-84.7	72.4	58.3-83.5
Total (*n*=27)	*n*=496	304.5	97	33.5	61	80.9	77.3-84.1	83.3	80.8-85.5	74.3	67.4-80.4