Nuclear medicine image interpretation by radiographers: Findings of an accredited postgraduate module

Manuscript type:

Original full length research paper

Authors:

P. Lockwood, G. Dolbear

Affiliations:

Clinical and Medical Sciences Research Hub, School of Allied Health Professions, Canterbury Christ Church University, Kent, UK

Introduction

At present, the UK is experiencing radiology service delivery difficulties, attested to by the Royal College of Radiologists (RCR)[1] workforce report of rising demand of imaging referrals (an estimated 30% increase in overall workload). Set against an estimated shortfall of reporting capacity of consultant radiologists[2,3] (1,000 consultant radiologist vacancies in 2017, predicted to be 1,600 by 2022[1]), in real terms, this equates to a large vacancy rate resulting in short term and unsustainable outsourcing of reporting costs (£58 Million in 2014 to £116 million in 2017[1]). The use of outsourcing also raises quality issues of alternative service provision[4] of poor quality reports, timeliness of reports, and communication difficulties between referrer and reporter. The RCR has warned this risks compromising patient safety in the long term, evidenced by only 3% of NHS trusts meeting national reporting timescales.[1] Nuclear Medicine (NM) has one of the lowest scores for same day reporting of all imaging modalities (36% in 2016-17[1]), due to in part by workforce shortages (109 consultant radiologists working primarily in NM, 44 have a secondary interest in NM) in 2017.[1]

These concerns have been escalated by the NHS Improvements organisation, bringing together a range of NHS teams and authorities to promote quality, service improvement and redesign (QSIR) tools[5] to improve operational performance priorities[6,7] and promote a culture of efficiency of NHS radiology services against increasing patient referrals.[8-11] This is supported by the Care Quality Commission[7] and NHS England[9] reviews that recommend QSIR projects to promote patient risk reduction policies and team working to improve the quality of clinical systems to support improved patient outcomes.

Diagnostic radiographers[12] are situated at the core of imaging services and are ideally placed to teamwork in partnership with consultant radiologists and promote service efficiencies through a higher level of radiographic practice[13,14] of post qualification skills and abilities learnt at local NHS trusts and in association with Higher Educational Institutes (HEIs). The Health and Care Professions Council (HCPC) regulating body for radiographers Standards of Proficiency[15] competencies reflects radiographer capabilities that can be applied to local service improvement and development to build imaging capacity provision in light of current demands. HCPC[15] standards of clinical practice underline radiographers capabilities and competencies of image interpretation (human anatomy and disease appearances relevant to their imaging modality[15]), with the promotion of these skills to assist in formulating plans if further action is required post imaging. The HCPC standards of education and training[16] likewise actively promote the partnership between HEIs and the profession to provide a range of traditional classroom learning and teaching as well as practice educational opportunities to develop these skills. Approval and accreditation of postgraduate opportunities are endorsed by the College of Radiographers (CoR)[17] that not only align to service improvement areas but radiographer career progression.[18] The CoR[19] further emphasise image interpretation skills and abilities of radiographers in clinical practice and promote it's potential to assist in apprising patient data and records to support initial clinical decision making in flagging unexpected findings to improve patient outcomes and service efficiencies.[20,21]

The Faculty of Health & Wellbeing at Canterbury Christ Church University is a major post-registration and continuing professional development health education provider for the south east of England and the national workforce. With pathways reflecting practice needs, and with the university ethos of partnership working with stakeholders in workforce development to design clinical curriculums, learning, teaching and assessments. The MSc Medical Imaging programme (part-time) provides a flexible educational provision in NM. The work-based clinical NM module (accredited 20 credits Level 7) includes a learning contract with clinical mentors for supervised weekly clinical practice sessions, and a clinical consultant radiologist assessor (1:1). The competency-based learning covers imaging and interpretation of bone, lung, renal and thyroid NM scans (including referral criteria, the technological principles of NM imaging equipment, radiopharmaceuticals, and anatomy, physiology, pathology, with consultant radiologist tutorials). The module assessments include a written case study, reflective audit essay, and image interpretation commentaries (60 formative, and 60 summative checked and assessed by consultant radiologists mentor and department clinical supervisors).

Aims

To evaluate the results of radiographers image interpretation commentaries of bone, lung, renal and thyroid NM examinations at the end of the nine month module. The task was not to produce a definitive clinical report, but an image interpretation and as such the postgraduate training reflected this role.

Method

This study received institutional research ethics and governance approval. Each participant provided informed consent to participate and submitted 60 mixed (bone, lung, renal and thyroid) summative image interpretation commentaries for assessment. The range of referral sources included acute and chronic referrals from in and outpatient pathways, GP and accident and emergency. The NM examinations consisted of prospective imaging worklists to reduce prevalence bias, and accurately reflect clinical practice.[22-23]

The radiographers had access to the patient's referral information (gender, age, clinical history, symptoms).[24-27] The NM image interpretations were completed independently, and prior to the consultant radiologist report, which was likewise blinded to the radiographer's commentary during the reporting of the examinations.[22,28,29] Each image interpretation was completed using a NM workstation at time of acquisition to reduce the variables (bias) of image quality compared to web client applications on standard computers. Dedicated NM workstations were the preferred option due to the specific software to support the evaluation and display of high-quality NM data (such as different views, phases, and multi-energy), and allow additional processing and registration of the data where differing voxel size, slice thickness, the field of view and matrix size occurs. This permitted navigation of the image sequences correctly, with a display of native and fused image sequences, multiplanar reformation, adjustable colour and transparency, the definition of regions of interest, and the semi-quantitative analysis of activity through calculating maximum and mean standardised uptake values.[30] Both the radiographers and consultant radiologists used the same NM workstations for data viewing, image commentary (radiographers) and definitive reporting (consultant radiologists).

Each of the radiographers recorded if the case was normal or abnormal and completed a free text commentary.[19,26] In abnormal judgements, the radiographers provided a written interpretation to identify abnormalities using descriptive terminology including anatomy, location and characteristics.[22,25] Normal cases incorporated, anatomical variants, abnormal cases included acute trauma, primary and secondary lesions, response to treatment, metabolic conditions, degeneration, infection, abnormal function, and congenital abnormalities (Table 1).

The scoring applied a two-step process, first each of the image interpretations were evaluated against the definitive consultant radiologist report (reference standard), and independently by each participant allocated clinical consultant radiologist assessor. Then the image interpretations were reviewed against the corresponding definitive consultant radiologist reports for second marking (internal consistency) at the university by three academic staff members (qualified and experienced NM radiographers at MSc and PhD level) for consensus agreement.[22,29] If the interpretation was correctly commented on as normal the radiographers were allocated a true negative (TN) whole mark (1.0). If a normal examination was incorrectly assessed as being abnormal, it was assigned a false positive (FP) score. If the radiographer identified an abnormality which was correct a true positive (TP) score would be allocated, or false negative (FN) score if the pathology was missed. Fractionated scoring was applied if multiple pathological conditions or locations (isotope uptake areas) were present, which permitted acknowledgement if some but not all abnormal conditions were recorded in the commentary. An example being an examination containing two equally significant lesions (concentration of tracer uptakes areas), and only one is commented upon by the radiographer. Thus the allocation of the point would be split to reflect 0.5 TP (the first lesion noted) and 0.5 FN (the second lesion missed). If four lesions were present each would be assigned 0.25 points, as described in a previous study.[31] Multiple pathological/physiological condition examples included chronic degenerative bone disease alongside acute primary and/or secondary bone tumours. Statistical analysis calculated sensitivity, specificity and accuracy, with 95% Confidence Intervals (95% CI)[22,32] using Wilsons method. Inter-observer variation and reliability was observed using Fleiss Kappa (k) for multiple reader agreements (taking into account agreement due to chance), with intraclass correlation coefficient (ICC) for the degree of association and reliability, applying two way random effects and absolute agreement, and Spearman's rank correlation coefficient (R_S) for strength and direction of association with standard error (SE).

Results

The study recruited 20 radiographers; demographics included 5 males (age range 26-33; mean 29.6 years), 15 females (age range 24-51; mean 31 years), with a range of NM experience (1-5 years in NM; mean 3.1 years). The clinical sites included 15 NM imaging departments of which 12 were district general hospitals, and 3 were large inner city hospitals. The abnormality prevalence (51.4%, Table 2), and the number of cases per examination category are displayed in Table 2. The NM examinations applied a range of radiopharmaceuticals dependant on department supply and department examination protocol. All intravenously injected and ventilated radiopharmaceuticals for the examinations followed the UK Administration of Radioactive Substances Advisory Committee (ARSAC) guidelines.[33]

The radiographer's (R1-R20) individual performance on bone scans image interpretations are displayed in Table 3, cohort sensitivity and specificity was 93% (95% CI 91.3-95.6) and 88% (95% CI 84.3-90.9) respectively, accuracy at 91.5% (95% CI 88.6-93.7). There was a strong agreement between radiographers with k=0.82, concordance displayed strong reliability at ICC=0.904, with a positive correlation direction R_S=0.826 (Table 4). Lung scans image interpretation by cohort demonstrated a sensitivity of 92.6% (95% CI 85.7-96.8), specificity was 92.1% (95% CI 88.7-94.1), accuracy 92.3% (95% CI 87.7-95.0) displayed in Table 5, with similar strength of agreement (reliability) of k=0.83, ICC=0.910, and R_S=0.835 (Table 4).

Renal scans image interpretation overall cohort sensitivity was 95% (95% CI 91.0-97.3), with 95.2% specificity (95% CI 91.8-97.3), accuracy of 95% (95% CI 91.4-97.3) shown in Table 6 (with individual R1-R20 figures). Further analysis and correlation displayed a high level of agreement k=0.90, ICC=0.948, and R_S=0.907 shown in Table 4. Thyroid scans cohort sensitivity was 88% (95% CI 83.1-91.4, although two radiographer's scores could not be calculated due to low case numbers), with 93% specificity (95% CI 85.9-96.8), accuracy was 90.2% (95% CI 84.3-93.8) displayed in Table 7. Fleiss's Kappa coefficient results (Table 4) produced an inter-observer agreement score of k=0.80 reflecting a good strength of agreement, ICC concordance scored highly with 0.897, and a positive correlation and direction were calculated (R_S=0.813).

The prospective natures of the worklist provided an imbalance in the frequency of abnormal scans (Table 2) which is reflected in the results. For example, ventilation and perfusion (V/Q) scans were often requested at short notice due to the urgent nature of Pulmonary Embolism (PE) referrals from the emergency department, as opposed to outpatient renal and thyroid scans. Due to this variation of factors, the data were pooled to display totals by exam category as well as individual results.

Discussion

The task of image interpretation and commentary in NM examinations differs from other diagnostic imaging modalities in that it primarily displays the physiological function of the system being examined as opposed to the structural anatomical characteristics. Moreover, a comparison of image interpretation in NM is difficult due to a lack of published studies. There are however published papers of radiographers providing definitive NM reporting tasks, such as Custis[34] for bone scans (98.5% agreement), lung V/Q scans (98.1% agreement) and renal scans (99.3% agreement). Svasti-Salee et al[35] of a single radiographer reporting lung V/Q scans (77% agreement; k=0.616), and Khonsari and Sulkin[36] establishing two radiographers reporting lung perfusion scans to 93% agreement (k=0.85). As well as the paper by Elliott[37] of a radiographer reporting a mix of radionuclide examinations at 90% accuracy, 91.5% sensitivity, and 89.4% specificity. These studies are inherently different in roles and education (definitive clinical reporting as opposed to image interpretation) so the comparison is not germane to these study results, but acknowledgement of levels of inter and intra-observer error and disagreement in interpretation of NM examinations are not solely found in radiographer studies but are evidenced in studies of medical reporters[38-40] and acknowledged by professional bodies.[24]

The analysis of the results within this study evidenced an ability to not only recognise abnormal uptake of tracer activity in the examinations but to also identify the possible causes, taking into account the clinical history by the referring physician and the distribution of the radioisotope. In TN bone scans commentaries recorded symmetrical characteristics around the midline and where the corresponding structures on the right and left of the body displayed equivalent activity. With areas of greater bone mass, such as the pelvis showed greater activity than thinner areas of bone such as the radius and ulna.

For whole body bone scans requested to identify possible bone metastasis, there can often be a dilemma in decision making between the causes of minor radionuclide hotspot collections that may reflect metabolic or degenerative joint disease as opposed to the presence of malignant spread of secondary bone tumours. There are many reasons for increased uptake of tracer activity on a bone scan ranging from metastases, Paget's disease, trauma, osteoarthritis or infection. A single lesion located in a peri-articular region may be considered likely to be benign, as opposed to being in the pedicle of a spinal vertebra potentially being a malignant metastasis. Further correlation to the clinical history or previous imaging can be helpful if available. Although, identification of minor degenerative changes mentioned by the radiographers was not always noted in the definitive report and raised issues with the perception of the consultant radiologist's view of the insignificance of common arthropathic changes. Particularly noted, were an osteoporotic vertebral collapse, minor changes in the acromioclavicular joints, bilateral shoulder joints, sacroiliac joint degeneration and the medial compartment of the knee. With the uptake of tracer activity not typical for the distribution of bony metastases spread (unlike tracer activity within ribs), often further imaging was requested in the definitive report to rule out benign conditions such as fibrous dysplasia, or rare instances of nonosseous uptake.[41] This being a clear difference in roles between the consultant radiologist definitive report and the role in this study for the radiographer's image interpretation.

In an FP case of an incorrectly stated pubic rami fracture, due to increased activity around the pubic rami, which was in fact from the bladder. A partial FN in the bone scan commentaries involved the recording of Pagets in the pelvis and lumbar spine but missed tracer uptake elsewhere within the skeleton, and a couple of cases where the radiographers identified the main primary hot spots but missed additional minor activity in the knee in multiple tracer uptakes throughout the whole skeleton. Furthermore, it was noted that there was occasional difficulty in describing the precise hotspot on bone scans due to the patient positioning. An example being isotope uptake in the foot and the radiographer's commentary approach of commenting on either the metatarsal or the foot, as patient motion and low count rates may make it difficult to ascertain the exact location in NM whole body bone scans.

The radiographer's ability in V/Q scans commentaries where the task was to rule out or confirm the presence or probability of pulmonary emboli (PE), reflected a good ability in recording the distribution of the tracer activity within the segments of the lungs. It is worth noting the radiographers had access to the view the prior chest radiograph, although mostly these were unreported, it has been evidenced this can assist the image interpretation task as noted by Khonsari and Sulkin.[36]

Minor FP errors found in the V/Q scan commentary included missing matched ventilation defects when attempting to locate evidence of PE. The viewing of V/Q scans is often categorised in radiologist reporting as high or low probability, but in difficult examinations agreement between reporters may lead to indeterminate results (cannot exclude a PE) which reflect the subjective nature of image interpretation in this examination type as also noted in a previous study by Custis.[34]

The evaluated results of the radiographer's renal image interpretations reflected high accuracy to the reference standard reports. All the TN MAG3 renogram examinations noted the slow passage of the tracer activity through the kidneys, but all commented on full 'washout' promptly following diuretic furosemide injection. When evaluating the kidney function for obstruction, the radiographer commentaries confirmed the renogram curves and renal differential percentages calculated from post-processing of the images. The static DMSA renal scans all scored TN, resulting in high specificity results in the investigation of renal scarring from recurrent urinary tract infections.

Thyroid scans TN cases reflected the uniform distribution of activity; a FP score was returned on a commentary of a cold nodule within a thyroid which was reported by the consultant radiologists as a TN examination. The parathyroid scans demonstrated a high specificity in the clinical referral for the investigation of adenomas, with no mismatch of isotope uptake. Additionally, access to previous ultrasound imaging assisted the radiographer's confirmation of pathology in relation to nodules.

In summary the results suggest radiograhers have a utility in service development through working at a higher level of radiographic practice, this can impact and influence improvements in service provision at a time when the NHS has pressures of workforce shortages and increasing referrral rates. Further work in updating the evidence of NM role development[13,14,34-37] of radiographers supported by professional policy[18,19,42] by the radiographic community would be beneficial to the UK healthcare system.

Limitations

Acknowledgement of the pilot study limits (sample of radiographers, prospective cases) provides constraints to a generalisation of the results. Likewise, a paucity of published evidence on radiographer image interpretation in NM narrows comparison of the pilot data.

Conclusion

In this small scale pilot study the aim was to investigate the image interpretation ability of radiographer's enrolled on a postgraduate module assessing bone, lung, renal and thyroid NM examinations in a clinical environment. The results were encouraging and displayed the radiographer's ability to complete the task in a clinical environment on prospective workloads.

Further research is required applying a larger bank of cases to assess ability after a delayed period of clinical experience, and exploration of the clinical utility downstream of applying image interpretation commentaries for fast-tracking urgent NM findings.

Word count 2994

References

1. The Royal College of Radiologists. Clinical radiology: UK workforce census 2017 report. The Royal College of Radiologists. September; 2018.
2. Centre for Workforce Intelligence. Securing the future workforce supply: Clinical radiology stocktake. London: Centre for Workforce Intelligence; December; 2012.
3. The Royal College of Radiologists. Clinical radiology: UK workforce census 2016 report. The Royal College of Radiologists. October; 2017.
4. The Royal College of Radiologists. Teleradiology and outsourcing census. The Royal College of Radiologists. May; 2010.
5. NHS Improvement. Quality, service improvement and redesign (QSIR) tools. [Accessed 16.09.2018] https://improvement.nhs.uk/resources/quality-service-improvement-and-redesign-qsir-tools/
6. The Care Quality Commission. The state of health care and adult social care in England 2016/17 (Presented to Parliament pursuant to section 83(4)(a) of the Health and Social Care Act 2008). Newcastle upon Tyne: House of Commons; 2017.
7. Department of Health. Improving outcomes: A Strategy for Cancer. London: HMSO; 2011.
8. NHS England. Diagnostic Imaging Dataset Statistical Release: Provisional monthly statistics, July 2016 to July 2017. November; 2017.
9. NHS England. Next steps on the NHS Five Year Forward View (Gateway number 06669). Leeds: NHS England; 2017.

10. The Kings Fund. Quality Monitoring Report November 2017: how is the NHS performing? The Kings Fund; 2017.
11. NHS Improvement. Quarter 2 2017/18 performance report: Performance of the NHS Provider Sector month ended 30 September 2017.
12. European Federation of Radiographer Societies. EFRS Definition of a radiographer. European Federation of Radiographer Societies; 2011.
13. Hogg P, Williams P, Norton S. Extended roles of radiographers working in nuclear medicine: a survey of current practice. Radiography 1997;3(3):179-90.
14. Hogg P, Holmes K. The interpretation of nuclear medicine data by non-medical health care professionals: developments in the United Kingdom. Journal of Diagnostic Radiography and Imaging. 2000;3(2).
15. The Health and Care Professions Council. Standards of Proficiency: Radiographers. London: The Health and Care Professions Council; 2013.
16. The Health and Care Professions Council. Standards of education and training. London: The Health and Care Professions Council; 2017.
17. Society and College of Radiographers. Approval and Accreditation Board Handbook. London: Society and College of Radiographers; 2009.
18. The Society and College of Radiographers. Education and Career Framework for the Radiography Workforce. London: SCoR; 2013.
19. Society and College of Radiographers. Preliminary Clinical Evaluation and Clinical Reporting by Radiographers: Policy and Practice Guidance. London: Society and College of Radiographers; 2013.
20. Woznitza N, Piper K, Rowe S, West C. Optimizing patient care in radiology through team-working: a case study from the United Kingdom. Radiography 2014; 20(3):258-63.
21. Welsh ME, Wakefield K, Holmes KG. The impact of radiographer reporting on the care and management of the patients in nuclear medicine. Nucl Med Commun 2005; 26(3):278.
22. Brealey S. Measuring the effects of image interpretation: an evaluative framework. Clinical radiology. 2001 May 1;56(5):341-7.
23. Hardy M, Flintham K, Snaith B, Lewis EF. The impact of image test bank construction on radiographic interpretation outcomes: A comparison study. Radiography 2016;31;22(2):166-70.
24. The Royal College of Radiologists. Audit Live Peer Review- Using Double Reporting as a Tool for Revalidation. London: The Royal College of Radiologists; 2010.
25. British Nuclear Medicine Society. Guidelines for the issue of reports by non-medical staff. BNMS; 2005.
26. Pinto A, Acampora C, Pinto F, Kourdioukova E, Romano L, Verstraete K. Learning from diagnostic errors: a good way to improve education in radiology. Eur J Radiol 2011; 30;78(3):372-6.
27. Berbaum KS, Franken JR EA, Anderson KL, Dorfman DD, Erkonen WE, Farrar GP, Geraghty JJ, Gleason TJ, Macnaughton ME, Phillips ME, Renfrew DL. The influence of clinical history on visual search with single and multiple abnormalities. Invest Radiol 1993; 1;28(3):191-201.
28. Brealey S, Scally AJ. Methodological approaches to evaluating the practice of radiographers' interpretation of images: a review. Radiography 2008:14; e46-54.
29. Brealey S, Scally AJ, Thomas NB. Methodological standards in radiographer plain film reading performance studies. Br J Radiol 2002;75(890):107-13.
30. van Ooijen PM, Jorritsma W. Medical Imaging Informatics in Nuclear Medicine. In Quality in Nuclear Medicine 2017:241-267.

31. Lockwood, P. Dolbear, G. Image interpretation by radiographers in brain, spine and knee MRI examinations: Findings from an accredited postgraduate module. Radiography 2018; 24: 370-375.
32. Scally AJ, Brealey S. Confidence intervals and sample size calculations for studies of film-reading performance. Clinical Radiology 2003;58(3):238-46.
33. Department of Health. Notes for Guidance on the Clinical Administration of Radiopharmaceuticals and Use of Sealed Radioactive Sources: Administration of Radioactive Substances Advisory Committee. Public Health England. Gateway number 2016613. February 2017. Oxon. UK.
34. Custis K. A study to assess the feasibility of introducing radiographer reporting in a nuclear medicine department. Nucl Med Commun 2006: 27(3):290.
35. Svasti-Salee D, Flanigan JJ, Conry BG, Wetton CW, Akhurst S. The reliability of radiographer based interpretation in acute reporting of V/Q scans: a prospective assessment. Nucl Med Commun 2004;25(4):408.
36. Khonsari M, Sulkin T. Audit of radiographer reporting of perfusion lung scans. Nucl Med Commun 2004;25(3):315.
37. Elliot, L. Radiographer reporting in the NM department: a learning curve? Radiography 2003; 9(3): 247-251.
38. Mckillop JH, Williams ED, Harding LK. Consistency in nuclear medicine reporting — a pilot study using bone scans. Nucl Med Commun 1990:11(3):253-258.
39. Lensing AW, van Beek EJ, Demers C, Tiel-van Buul MM, Yakemchuk V, van Dongen A, Coates G, Ginsberg JS, Hirsh J, ten Cate JW, Büller HR. Ventilation-perfusion lung scanning and the diagnosis of pulmonary embolism: improvement of observer agreement by the use of a lung segment reference chart. Thrombosis and haemostasis 1992;68(03):245-9.
40. Patel K, Charron M, Hoberman A, Brown ML, Rogers KD. Intra-and interobserver variability in interpretation of DMSA scans using a set of standardized criteria. Pediatr Radiol 1993:1;23(7):506-9.
41. Zuckier LS, Freeman LM. Nonosseous, Nonurologic Uptake on Bone Scintigraphy: Atlas and Analysis. Semin Nucl Med 2010; 40:242-256.
42. The Royal College of Radiologists. Standards for interpretation and reporting of imaging investigations (second edition). The Royal College of Radiologists. March; 2018.

Table 1. Abnormality referral categories.

Bone Scans	**Lung scans**	**Renal scans**	**Thyroid scans**
Primary bone tumours	Chest pain	Renal function	Abnormal function
Metastatic staging	Shortness of breath	Bladder dysfunction	Primary hyperparathyroidism
Response to radiotherapy	Positive d-dimer test	Trauma	Thyrotoxicosis
Response to chemotherapy	Hypertension	Reflux neuropathy	Parathyroid adenoma
Bone pain	Low saturation	Recurrent infection	
Trauma	Pulmonary embolism	Hydronephrosis	
Metabolic bone disease	Pre-lobectomy lung function	Pyelonephritis	
Degenerative bone disease		Obstruction	
Paget's		Scarring of the cortex	
Sacroiliitis		Primary lesions	
Osteomyelitis		Renal failure	
Osteomalacia		Congenital abnormalities	
Avascular necrosis			
Loosening/infection of prosthesis			

Table 2. Disease prevalence ratio.

	Number of cases		
	Total	***Normal***	***Abnormal***
Bone scans	519	205 (39.5%)	314 (60.5%)
Lung scans	226	152 (67.3%)	74 (32.7%)
Renal scans	282	151 (53.5%)	131 (46.5%)
Thyroid scans	173	75 (43.4%)	98 (56.6%)
All Exams	1,200	583 (48.6%)	617 (51.4%)

Table 3. Bone scan image interpretation results.

Radiographer	*Cases*	*TP*	*FP*	*FN*	*TN*	*Sensitivity*	*.95% CI*	*Specificity*	*.95% CI*	*Accuracy*	*.95% CI*
R1	*n*=38	13	3	0.5	21.5	96.3	73.9-100	87.8	75.4-89.8	90.8	74.9-93.4
R2	*n*=38	28.75	1.5	2.75	5	91.3	83.1-95.4	76.9	37.2-97.0	88.8	75.2-95.7
R3	*n*=28	24.5	0.5	0	3	100	92.2-100	85.7	30.8-85.7	98.2	84.5-98.2
R4	*n*=42	35	0	1	6	97.2	85.4-99.9	100	54.0-100	97.6	86.0-97.6
R5	*n*=20	14.5	0	1.5	4	90.6	77.0-90.6	100	45.5-100	92.5	70.7-92.5
R6	*n*=25	15	0	0	10	100	78.1-100	100	96.1-100	100	80.6-100
R7	*n*=31	10	2	1	18	90.9	58.7-99.7	90.0	68.3-98.7	90.3	71.6-96.4
R8	*n*=27	18	0	4.5	4.5	80.0	69.5-80.0	100	47.4-100	83.3	65.8-83.3
R9	*n*=20	6.5	2.5	0	11	100	61.7-100	81.5	63.0-81.5	87.5	62.6-87.5
R10	*n*=22	15	2	0	5	100	78.1-100	71.4	29.0-96.3	90.9	69.5-90.9
R11	*n*=29	15	1	1	12	93.7	69.7-99.8	92.3	63.9-99.8	93.1	73.7-99.4
R12	*n*=19	11	0	2	6	84.6	54.5-98.0	100	54.0-100	89.5	63.9-89.5
R13	*n*=28	12	1	1	14	92.3	63.9-99.8	93.3	68.0-99.8	92.9	72.8-99.4
R14	*n*=24	9	1	1	13	90	55.4-99.7	92.8	66.1-99.8	91.7	69.2-99.3
R15	*n*=9	4	0	0	5	100	39.7-100	100	47.8-100	100	56.8-100
R16	*n*=20	13	0	0	7	100	75.2-100	100	59.0-100	100	56.8-100
R17	*n*=27	10	4	0	13	100	69.1-100	76.4	50.1-93.1	85.2	64.7-85.2
R18	*n*=19	14	2	0	3	100	76.8-100	60	14.6-94.7	89.5	68.9-89.5
R19	*n*=33	14.5	3	1.5	14	90.6	71.1-98.8	82.4	64.0-90.0	86.4	67.5-94.3
R20	*n*=20	12	1	2	5	85.7	57.1-98.2	83.3	35.8-99.5	86.4	67.5-94.3
All	*n*=519	294.75	24.5	19.75	180	93	91.3-95.6	88	84.3-90.9	91.5	88.6-93.7

Table 4. Kappa (k), intraclass correlation coefficient (ICC), and Spearman's rank correlation coefficient (RS) with standard error (SE).

	K	*95%CI*	*ICC*	*95%CI*	R_S	*SE*
Bone Scan cases (*n*=519)	0.82	(0.770-0.871)	0.904	(0.886-0.919)	0.826	0.025
Lung Scan cases (*n*=226)	0.83	(0.751-0.905)	0.910	(0.883-0.931)	0.835	0.038
Renal Scan cases (*n*=282)	0.90	(0.849-0.951)	0.948	(0.935-0.959)	0.907	0.025
Thyroid Scan cases (*n*=173)	0.80	(0.712-0.891)	0.897	(0.861-0.924)	0.813	0.044
All cases (*n*=1,200)	0.84	(0.815-0.875)	0.917	(0.907-0.926)	0.846	0.015

Table 5. Lung scan image interpretation results.

Radiographer	*Cases*	*TP*	*FP*	*FN*	*TN*	*Sensitivity*	*.95% CI*	*Specificity*	*.95% CI*	*Accuracy*	*.95% CI*
R1	*n*=5	3	0	0	2	100	29.2-100	100	15.8-100	100	40.6-100
R2	*n*=10	1	0	0	9	100	2.5-100	100	66.3-100	100	81.2-100
R3	*n*=7	5	0.5	0	1.5	91.3	83.1-95.4	76.9	37.2-97.0	90	52.4-90
R4	*n*=9	1	0	0	8	100	2.5-100	100	63.0-100	100	79.1-100
R5	*n*=21	9.5	2	0.5	9	95	68.6-100	81.8	57.8-86.4	88.1	62.9-92.9
R6	*n*=6	1	0	0	5	100	2.5-100	100	47.8-100	100	68.6-100
R7	*n*=7	1	0	0	6	100	2.5-100	100	54.0-100	100	73.1-100
R8	*n*=16	3	0	3	10	50	11.8-88.1	100	69.1-100	81.3	56.7-81.3
R9	*n*=24	12	1	1	10	92.3	63.9-99.8	90.9	58.7-99.7	91.7	69-99.3
R10	*n*=16	2.5	0.5	0	13	100	29.8-100	96.3	83.3-96.3	96.9	75-96.9
R11	*n*=13	4	1	0	8	100	39.7-100	88.8	51.7-99.7	92.3	60-92.3
R12	*n*=13	5	2.5	0	5.5	100	56.0-100	68.8	41.2-68.8	80.8	46.9-80.8
R13	*n*=10	1	0	1	8	50	1.2-98.7	100	63.0-100	90	71.1-90
R14	*n*=11	4	1	0	6	100	39.7-100	85.7	42.1-99.6	90.9	53.5-90.9
R15	*n*=10	6	1	0	3	100	54.0-100	75	19.4-99.3	90	52.4-90
R16	*n*=10	1	0	0	9	100	2.5-100	100	66.3-100	100	81.2-100
R17	*n*=13	1	2.5	0	9.5	100	5.6-100	79.2	71.3-79.2	80.8	66.2-80.8
R18	*n*=10	5	0	0	5	100	47.8-100	100	47.8-100	100	59.6-100
R19	*n*=5	1	0	0	4	100	2.5-100	100	39.7-100	100	62.3-100
R20	*n*=10	2	0	0	8	100	15.8-100	100	63.0-100	100	69.3-100
All	*n*=226	69	12	5.5	139.5	92.6	85.7-96.8	92.1	88.7-94.1	92.3	87.7-95

Table 6. Renal scan image interpretation results.

Radiographer	*Cases*	*TP*	*FP*	*FN*	*TN*	*Sensitivity*	*.95% CI*	*Specificity*	*.95% CI*	*Accuracy*	*.95% CI*
R1	*n*=11	3	0	0	8	100	29.2-100	100	63.0-100	100	66.4-100
R2	*n*=6	3.5	0.5	0	2	100	56.7-100	80	19.4-80	91.7	41.1-91.7
R3	*n*=10	3.75	3.75	1.25	1.25	75	52.3-97.7	25	2.3-47.7	50	27.3-72.7
R4	*n*=5	2	0	0	3	100	15.8-100	100	29.2-100	100	40.6-100
R5	*n*=10	7	0	0	3	100	59.0-100	100	29.2-100	100	63.2-100
R6	*n*=14	7	0	0	7	100	59.0-100	100	59.0-100	100	68.5-100
R7	*n*=15	2	0.5	0.5	12	80	17.3-100	96	83.5-100	93.3	72.4-100
R8	*n*=10	2.5	0	0.5	7	83.3	25.5-83.3	100	75.2-100	95	60.3-95
R9	*n*=12	1	0	1	10	50	1.2-98.7	100	69.1-100	91.7	75.9-91.7
R10	*n*=15	8	0	0	7	100	63.0-100	100	59.0-100	100	70.2-100
R11	*n*=10	5	0	0	5	100	47.8-100	100	47.8-100	100	59.6-100
R12	*n*=16	6	1	0	9	100	54.0-100	90	55.4-100	100	70.6-100
R13	*n*=11	4	1	0	6	100	39.7-100	85.7	42.1-99.6	90.9	53.5-90.9
R14	*n*=20	9	0	0	11	100	66.3-100	100	71.5-100	100	76.4-100
R15	*n*=32	21	0	1	10	95.4	77.1-99.8	100	69.1-100	96.9	80.4-96.9
R16	*n*=21	12	0	0	9	100	73.5-100	100	66.3-100	100	77.4-100
R17	*n*=13	5	0	0	8	100	47.8-100	100	63.0-100	100	67.4-100
R18	*n*=16	11	0	0	5	100	71.5-100	100	47.8-100	100	73-100
R19	*n*=15	3	0.5	0.5	11	85.7	30.5-100	95.7	78.8-100	93.3	67.6-100
R20	*n*=20	9	0	2	9	81.8	48.2-97.7	100	66.3-100	90	64.6-90
All	*n*=282	124.75	7.25	6.75	143.25	95	91.0-97.3	95.2	91.8-97.3	95	91.4-97.3

Table 7. Thyroid scan image interpretation results.

Radiographer	*Cases*	*TP*	*FP*	*FN*	*TN*	*Sensitivity*	*.95% CI*	*Specificity*	*.95% CI*	*Accuracy*	*.95% CI*
R1	*n*=6	3	1	0	2	100	29.2-100	66.6	9.4-99.1	83.3	33-83.3
R2	*n*=6	3	0	0	3	100	29.2-100	100	29.2-100	100	43.6-100
R3	*n*=15	7.5	1.5	2	4	78.9	55.3-92.4	72.7	31.9-96	76.7	6.7-93.8
R4	*n*=4	0	0	0	4	—	—	100	100-100	100	100-100
R5	*n*=9	6	1	1	1	85.7	42.1-99.6	50	1.2-98.7	77.8	56.8-98
R6	*n*=15	10	0	2	3	83.3	51.5-97.9	100	29.2-100	86.7	60.7-86.7
R7	*n*=7	4	1	1	1	80	28.3-99.4	50	1.2-98.7	71.4	44.4-97.4
R8	*n*=7	1	0	0	6	100	2.5-100	100	54.0-100	100	73.1-100
R9	*n*=4	1	0	0	3	100	2.5-100	100	29.2-100	100	52.9-100
R10	*n*=7	5	0	1	1	83.3	35.8-99.5	100	2.5-100	85.7	58.8-85.7
R11	*n*=8	5	0	0	3	100	47.8-100	100	29.2-100	100	54.9-100
R12	*n*=12	6	0.5	0	5.5	100	64.1-100	91.7	55.7-91.7	95.8	59.9-95.8
R13	*n*=11	1	0	2	8	33.3	0.8-90.5	100	63.0-100	81.8	64.7-81.8
R14	*n*=5	0	0	0	5	—	—	100	100-100	100	100-100
R15	*n*=9	6	0	0	3	100	54.0-100	100	29.2-100	100	59.4-100
R16	*n*=9	3	0	1	5	75	19.4-99.3	100	47.8-100	88.9	47.6-88.9
R17	*n*=7	4	0	0	3	100	39.7-100	100	29.2-100	100	49.5-100
R18	*n*=15	9	0	1	5	90	55.4-99.7	100	47.8-100	93.3	63.4-93.3
R19	*n*=7	5	0.5	0.5	1	90.9	73.7-100	66.7	3.7-100	85.7	58.7-100
R20	*n*=10	7	0	0	3	100	59.0-100	100	29.2-100	100	63.2-100
All	*n*=173	86.5	5.5	11.5	69.5	88	83.1-91.4	93	85.9-96.8	90.2	84.3-93.8