Efficacy, utility, and validity in Computed Tomography head reporting by radiographers

by

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Abstract

Introduction: Demand for Computed Tomography (CT) head imaging has increased exponentially within the National Health Service (NHS) coinciding with a limited consultant radiologist workforce, resulting in time-critical CT reporting delays for patients. The safety and effectiveness of the NHS improvement initiative increasing reporting capacity with radiographers is not yet established.

Aim: To establish the diagnostic accuracy (efficacy) of trained radiographers reporting CT head examinations; their role in the patient pathway (clinical utility); beneficial outcomes of radiographers' reports (validity); and an economic assessment of the role.

Methods: A literature review using validated critique frameworks assessing methodological quality (QUADAS-2, CASP, CHEERS) and reporting (STARD, StaRI) of radiographers reporting CT head examinations studies established the 'knowledge gap' in evidence and requirement for research rigour. A further literature review identified an efficacy framework to structure the pragmatic mixed-method research strategy. Seven studies assessed diagnostic accuracy, radiographers' roles within the NHS, and economic evaluation, against the same frameworks to demonstrate research rigour.

Results: Radiographers trained to report CT head scans demonstrated an efficacy level (AUC 0.98) equivalent to consultant radiologists. Radiographers communicated actionable reports and advice to multidisciplinary teams aiding clinician's decisions including medical interventions and surgical referral evidencing clinical utility. Cross-sectional surveys demonstrated radiographers' scope of practice included all referral pathways of trauma, health screening, disease diagnosis, staging, and monitoring treatment, and patient groups. The role was cost-effective (up to £328,865 per annum, per radiographer) and contributed a cost-benefit, attesting to the validity of the role within the patient pathway and healthcare system.

Conclusion: Novel findings evidence trained CT head reporting radiographers' efficacy is equivalent to radiologists, with beneficial impact for service design and delivery of expanding the workforce safely to potentially reduce reporting delays. An emerging theme from the findings underscores the need for robust study design to generate translational evidence for clinical practice.

Acknowledgements

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I would like to thank my PhD Chair of Studies Dr Kate Springett, and my PhD Supervisor Dr Alison Eyden, for their generous time, support and wisdom during the final year thesis write up.

I would also like to thank Dr Keith Piper for his support and mentorship at the start of this research journey back in 2014.

I would finally like to thank the 386 radiographers, 11 consultant radiologists, and all the NHS Trusts who participated in the research between 2014 - 2019.

Declaration of Originality

I hereby declare that **Paul Lockwood** has completed this thesis under the support and guidance of a dedicated team of supervisors at Canterbury Christ Church University for the award of Doctor of Philosophy through the route of PhD by Publication.

This thesis includes seven original studies published in peer-reviewed journals. The core theme of the thesis is centred on the original research in CT head reporting by radiographers. Each study has been granted the appropriate level of ethical approval.

I have maintained the confidentiality of participants throughout the research, and I have correctly and adequately acknowledged the significant contribution and made reference to supporting texts.

Signature____Date___27.04.2021____________

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Study 2. Lockwood, P. (2017) ‘CT sinus and facial bones reporting by radiographers: findings of an accredited postgraduate programme’, *Dentomaxillofacial Radiology*, 46(5), 20160440, pp.1-11.

Study 3. Lockwood, P. (2017) ‘Observer performance in Computed Tomography head reporting’, *Journal of Medical Imaging and Radiation Sciences*, 48(1), pp. 22-29.

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Glossary of abbreviations

A&E	Accident and Emergency
ABI	Acquired Brain Injury
ACC	Accuracy
ACR	American College of Radiologists'
AFROC	Alternative Free-response Receiver Operating Characteristic
AHRQ	Agency for Healthcare Research and Quality
ANOVA	Analysis of Variance
AUC	Area Under the Curve
BIR	British Institute of Radiology
BMA	British Medical Association
CASP	Critical Appraisal Skills Programme
CHEERS	Consolidated Health Economic Evaluation Reporting Standards
CI	Confidence Interval
CINAHL	Cumulative Index to Nursing and Allied Health Literature
COR	College of Radiographers
CPD	Continuing Professional Development
CQC	Care Quality Commission
CT	Computed Tomography
DoH	Department of Health (pre-2018)
DOR	Diagnostic Odds Ratio
EQUATOR	Enhancing the QUAlity and Transparency Of health Research
GE	General Electric
GMC	General Medical Council
GIRFT	Getting It Right First Time

HCPC	Health and Care Professions Council
ICER	Incremental Cost-Effectiveness Ratio
LR	Likelihood Ratios
K	Kappa
MEDLINE	Medical Literature Analysis and Retrieval System Online
MDT	Multi-Disciplinary Team
MRC	Medical Research Council
MRI	Magnetic Resonance Imaging
MRMC	Multi-Reader Multi-Case
NDIB	National Diagnostics Imaging Board
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NM	Nuclear Medicine
PAs	Programmed Activities
PACS	Picture Archiving and Communications System
Paed	Paediatric patient
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PubMed	Public/Publisher MEDLINE
QALY	Quality Adjusted Life Years
QUADAS-2	QUality Assessment of Diagnostic Accuracy Studies 2
RCR	Royal College of Radiologists
ROC	Receiver Operating Characteristic
SE	Standard Error
Sens	Sensitivity
SCoR	Society and College of Radiographers
SIG	Special Interest Group

Spec	Specificity
sROC	Summary Receiver Operating Characteristic
STARD	STAndards for Reporting Diagnostic accuracy studies
StaRI	Standards for Reporting Implementation studies
TATs	Turnaround Times
TBI	Traumatic Brain Injury
TIA	Transient Ischaemic Attack
UK	United Kingdom
UKRC	United Kingdom Radiological Congress
US	Ultrasound

Glossary of Terms

Accuracy – Diagnostic accuracy studies assess how good a test is at discriminating between patients with a disease from those without a disease (Maisey & Hutton, 1991).

Agreement – A measure of the reliability and concordance of agreement of a diagnosis between two or more reporters (observers).

Analytical Validity – The same as 'Technical Efficiency' as a test measurement performance in a controlled (laboratory) environment (CDCP, 2010).

Area Under the Curve (AUC) – The measurement of accuracy in a Receiver Operating Characteristic (ROC) test defining the discrimination (the ability of the image reader) to correctly classify disease or normal anatomy from a test bank of medical imaging cases.

Clinical Utility – The assessment of the reporting role effect on diagnostic thinking efficacy, i.e. the role within the patient pathway, and the relationship of communicating results to clinicians in effecting decisions on patient treatment and management. (CDCP, 2010)

Clinical Validity – Also known as 'Diagnostic Accuracy Efficacy', an assessment against defined characteristics such as Accuracy, Sensitivity and Specificity to distinguish patients with and without target conditions (Fryback & Thornbury, 1991).

Computed Tomography (CT) - A medical imaging examination that uses X-rays to produce cross-sectional images of human anatomy to display the inside organs and tissue structures for diagnosis of a range of acute and chronic conditions.

Cost-Effective – A form of economic analysis that compares the relative costs and outcomes in monetary value of introducing an intervention (in this example radiographers' reporting role) against the existing standard (consultant radiologists) to question the value, the benefits, and cost-efficient use of healthcare resources.

Cost-Benefit - The potential societal level cost savings (Fryback & Thornbury, 1991) an analysis to compare interventions (radiographers and radiologists) in both costs and the resulting benefits (healthcare outcomes such as reduced backlogs, faster treatment in time-critical conditions, reduction of long-term disabilities from delayed treatment in terms of societal level costs such as quality of life).

Cumulative Advantage – In economics, the term implies an increased or increasing benefit and argument to applying the intervention under examination, as it provides a favourable outcome and opportunity for improvement of healthcare service.

Diagnostic Accuracy Study – An empirical research study assessing radiographers reporting a validated bank of medical images in a controlled (laboratory) environment as part of a postgraduate course. The test assesses the ability to correctly discriminate and identify normal (healthy patients) from abnormal (target conditions of disease in patients) (Brealey, Scally & Thomas, 2002).

Diagnostic Performance Study – An empirical research study assessing radiographers reporting ability through an audit mechanism in clinical practice. (Brealey, Scally & Thomas, 2002).

Diagnostic Outcome Study - An empirical cohort comparison study assessing radiographers reporting outcomes compared to another cohort of trained reporters (normally consultant radiologists) against a validated bank of medical images (Brealey, Scally &Thomas, 2002).

Diagnostic Thinking Efficacy – The influence of the imaging report and communication upon the diagnostic thinking of the referring doctor (downstream clinical judgements). Assessing the effect of the report to help doctor's diagnosis, change in probability of a pre-test estimate, and influence on medical / surgical treatment (therapeutic effect), management plan, and patient outcomes (Fryback & Thornbury, 1991).

Diagnostic Efficacy – The ability to detect and differentiate between positive (abnormal) and negative (normal) patient conditions.

Efficacy – A medical term for the ability to achieve or perform a task to a satisfactory, beneficial, or expected result, similar to the term effectiveness.

Patient Outcome Efficacy – Does the patient benefit from the test than if they had not been tested (Fryback & Thornbury, 1991), it is an estimation of the increased benefits to patients' management and treatment (outcomes) from having the scan and report.

Picture Archiving and Communications System (PACS) – A combination of computer software and hardware designed to store, display, and distribute medical imaging.

Receiver Operating Characteristic (ROC) – A statistical test designed to measure the ability of a reader to make important distinctions between normal/abnormal human anatomy in medical imaging tests.

Reference Standard – The measure of the value assigned to the quality of imaging answers used in the tests, as set by a selection of qualified practitioners.

Referring Clinician – A qualified healthcare practitioner (usually a Doctor or Advanced Practice Stroke Nurse) that refers patients for medical imaging.

Reporting Radiographer – A diagnostic radiographer with postgraduate training and qualification to report medical images at an advanced practice role in a clinical radiology department (SCoR, 2013).

Sensitivity - A test's ability to correctly identify those with a disease (true positive rate).

Specificity - A test's ability to correctly identify those without a disease (true negative rate).

Societal Efficacy – The cost-benefit and cost-effectiveness of the report (Fryback & Thornbury, 1991).

Technical Efficacy – In a controlled laboratory setting, does the test measure what it purports to measure (Fryback & Thornbury,1991).

Therapeutic Efficacy – The influence upon the patient clinical treatment and management plans (Fryback & Thornbury 1991), and consideration of if the patient would be better off as a result of having the CT scan and report or without (Loop & Lusted, 1978).

Section 1

1.0 Introduction

Computed Tomography (CT) head imaging is a critical step in the patient pathway to diagnose and manage neurological brain conditions. Demand for imaging has increased beyond radiologist workforce capacity (RCR, 2012a – 18a) resulting in delays in diagnosing neurological conditions. A National Health Service (NHS, 2003) improvement initiative involved training radiographers in reporting CT head examinations to assist the service demand. There appears to be limited literature evidencing the effect of radiographer reporting CT head scans and this thesis explores the efficacy, clinical utility, validity and economic impact of radiographers reporting CT head examinations.

This thesis consists of three sections (concept mapping provided in appendix 1). Section 1 (1.1 - 1.2) situates the historical and contemporary context of radiographer reporting role development, underpinned by the pressures of increasing patient demand, resource scarcity of the radiologist workforce, and delayed CT report turnaround times (TATs). Subsections 1.3 - 1.8 establish the research aims and methodology. In this regard, a literature review identifies the research approach of an efficacy framework. In subsections 1.9 – 1.11 a further literature review identifies the 'gap in the existing knowledge' that substantiates the need for research into the efficacy, clinical utility, validity, and cost of radiographers reporting CT head examinations.

Section 2 (2.0 – 2.7), critically appraises and reviews the seven submitted studies on trained radiographers' technical efficacy (accuracy) in academic environments (studies 1 - 2) and diagnostic efficacy in clinical settings (study 3 - 4). The clinical utility (the role within the patient pathway), validity (the role within the service delivery), the impact on diagnostic thinking efficacy (studies 5 - 6), and associated costs (study 7) are reviewed against critique frameworks (1.9) of methodological standards, rigour, originality, and significance. Section 2 (2.8 – 2.9), concludes with a meta-analysis and synthesis of the research's strengths and weakness.

Section 3 (3.0 – 3.2) explores the research contribution to new knowledge, practice, and policy implications with recommendations for future research, and conclusion and reflection of the thesis findings', translational aspects, and clinical practice implications.

1.1 Historical context of reporting by radiographers

As a profession, radiography originated in 1920 with the Society of Radiographers (SoR) establishing qualifications and standards of practice, of which reporting diagnosis was commonplace (Larkin, 1983; Price & Paterson, 2020). Between 1923 and 1925, the General Medical Council (GMC) and the British

Medical Association (BMA) pressured a resolution to Article 27 of the Articles of Association to legally prevent radiographers from providing reports and diagnoses from X-ray examinations (BMJ, 1903;1909; Holland, 1917; Kempster, 1917; Lay, 1917; BMA, 1917; Hernaman-Johnson, 1919; Moodie, 1969; Price, 2000).

In 1977, the College of Radiographers (CoR) was formed to oversee education and professional responsibility (forming the joint Society and College of Radiographers (SCoR). The CoR amended Article 21 of the 'Articles of Association for Radiographers' (1977) to legally allow diagnostic radiographers to report Ultrasound (US) examinations. This critical and consequential shift in the scope of practice was supported by the 'Code of Professional Conduct' (1988, p.4) "*A radiographer may provide a description of images, measurements and numerical data*".

The NHS drive for patient-focused improvements through reform and White Paper policies such as 'Health of the Nation' (1992) prompted pilot trials by Saxton (1992), Chapman (1992) and Loughran (1994; 1996) to progress radiographer practice further, supported by the CoR amendment of the 'Code of Professional Conduct' (1994), to allow radiographers to provide both verbal and written reports on images. The following year, the Audit Commission Report (1995) evidenced that backlogs in reporting due to limited radiologist workforce impacted patient treatment and management. In response, the CoR accredited the first postgraduate reporting programmes in musculoskeletal X-ray for radiographers at Canterbury Christ Church, Bradford, Hertfordshire, Leeds, London South Bank, and Salford universities.

Research on education, assessment and clinical practice followed providing the evidentiary basis to support NHS clinical practice of X-ray reporting by radiographers in studies by Robinson (1996); Loughran (1996); Robinson et al. (1999); Brealey et al. (2003; 2005); Piper et al. (2005); Hardy and Snaith, (2011); Hardy et al. (2013; 2016); and Culpan et al. (2019). The role of radiographer reporting has since gained interdisciplinary stakeholder endorsement as a professions mix approach to medical imaging reporting (CoR 1997; 1998; 2006; 2010; 2012; 2013; 2014; Department of Health (DoH), 2003; 2010; 2011; Royal College of Radiologists (RCR) and SCoR, 1998; 2012).

In summary, radiographer reporting of X-rays in the NHS is now standard practice and endorsed by the DoH Radiography Skills Mix report (2003), advocating the need to redesign service delivery (NHS Plan, 2000a; NHS Cancer Plan, 2000b) to decrease patient delays and improve health outcomes. The Skills Mix report (2003) helped drive the expansion of the reporting radiographer further into CT head reporting (Craven & Blanshard, 1997), barium enemas (Mannion et al., 1995), mammography (Pauli et al., 1996), Magnetic Resonance Imaging (MRI) (Slavotinek & Kurmis, 2000) and Nuclear Medicine (NM) (Hogg & Holmes, 2000).

1.2 Contemporary context of CT head reporting by radiographers

The influence and impact of the NHS Plan (2000a) and Radiography Skills Mix (2003) initiatives led to partnership development between local NHS trusts, and UK universities offering postgraduate education in CT head reporting by radiographers. This initiative helped address the increased demand of CT image reporting and radiologist workforce shortages which mirrored the X-ray reporting delays in the 1990s (1.1). CT head reporting by radiographers continues to receive stakeholder support for the role by the SCoR, 2015; 2017a; 2017b; the SCoR and RCR, 2015; the SCoR, British Institute of Radiology (BIR) and InHealth, 2017; NHS England, 2018; Care Quality Commission (CQC), 2018; Getting It Right First Time (GIRFT), 2020.

Demand for CT imaging has increased over the last ten years (2010 - 2020) of 49% in England (NHS England, 2014; 2020) due to the largest population in the UK, with rises in the smaller nations of 33% in Wales (Wales Audit Office, 2018), 63% in Scotland (NHS Scotland, 2020) and 49% in Northern Ireland (Health Service Northern Ireland, 2020) (figure 1).

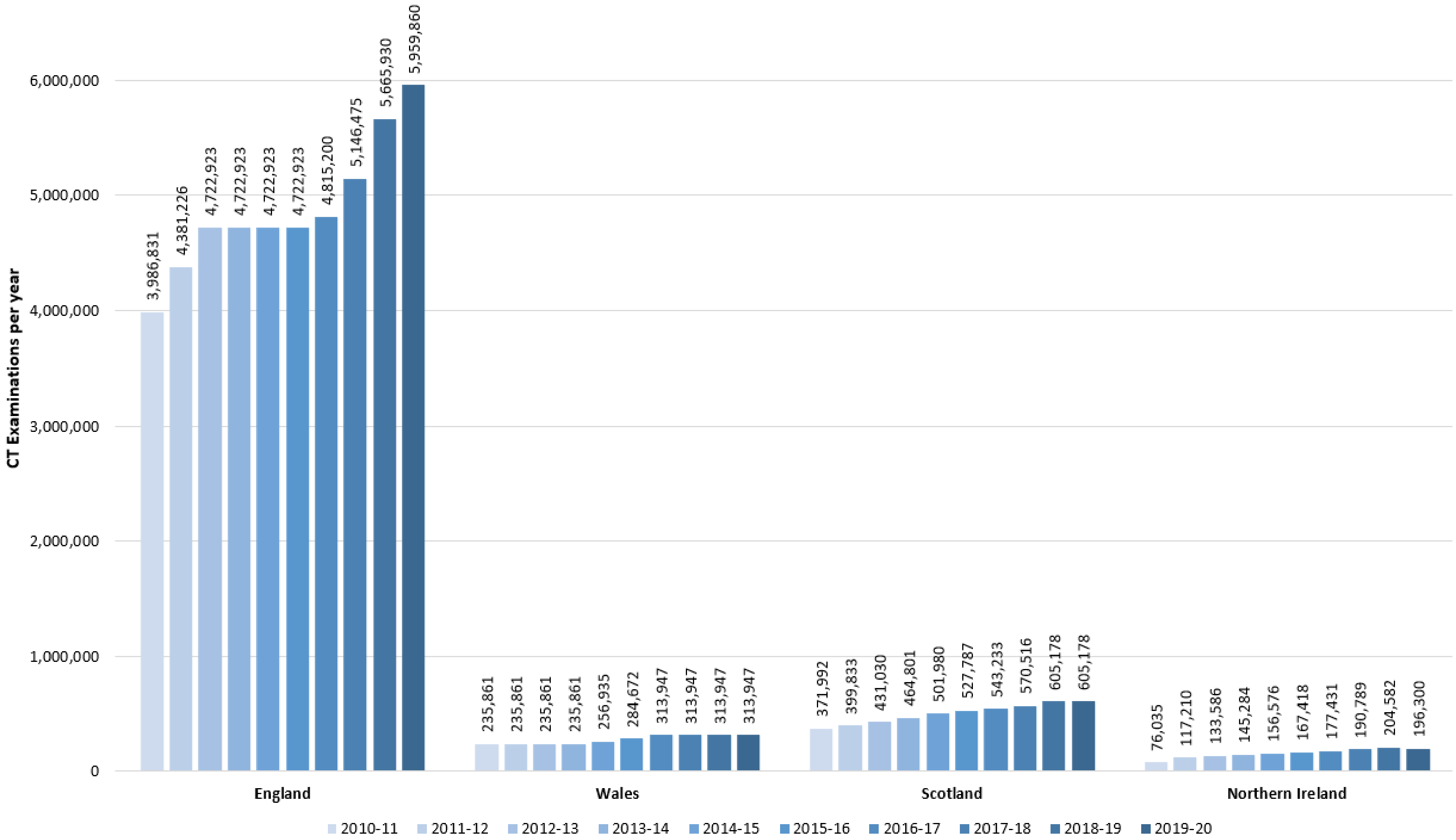


Figure 1. 10 Year UK data trend of CT imaging demand (NHS 2014a; 2014b; 2015; 2016; 2017a; 2018; 2019b; 2020a; Wales Audit Office 2018; NHS Scotland 2017; Health Service Northern Ireland 2020).

Extensive reporting delays in CT imaging have resulted from increased patient demand in conjunction with radiologist workforce shortage of 33% in the UK over the same time (RCR, 2012a – 18a; GE, 2018). The RCR (2016a, p.7) assert that "*Insufficient radiologists, substantial growth in the numbers of imaging tests (CT and MRI in particular) and the increased complexity of imaging have resulted in nearly all radiology departments (97%) in the UK having been unable to meet their reporting requirements within contractual hours*", with more than 85% of UK radiology departments' reporting workload not being completed to TATs (RCR, 2012a).

Within the UK, statutory legislation (Ionising Radiation Medical Exposure Regulations, 2000c; 2017) requires all medical imaging examinations to have a diagnostic report. This is reiterated by the National Patent Safety Agency (2007), the RCR (1995a), the CQC (2018), the Healthcare Safety Investigation Branch (2019), and GIRFT (2020) for all medical imaging to have timely, accurate and appropriate written reports. Reporting TAT targets from the time of imaging (examination) to the report (diagnosis) issued is set by National Diagnostics Imaging Board (NDIB, 2008) standards. The TAT report standards for urgent imaging is within 30 minutes, inpatient and A&E patient imaging the same working day, and ideally all other imaging referrals, including outpatients, to be reported by the next working day (NDIB, 2008). Specifically, for CT head examinations, the National Institute for Health and Care Excellence (NICE) Head Injury guidelines (2007; 2014a; 2020a) recommend a report within 1 hour of imaging. The NICE Stroke guidelines (2008; 2019; 2020b) advise CT head reporting within 1 hour of hospital admission, mirroring NHS Stroke TAT targets (NHS, 2014; 2017b; 2019).

However, published CT reporting TATs from NHS England (2012 – 2020) document only 65% of CT scans were reported within the 2-day TAT target; the ramifications were 35% of CT reports breached the NDIB (2008) and NICE (2020a) report TAT standards, with patient outcomes suffering as a consequence (RCR, 2016b). The Health Service Northern Ireland (2010 - 20) disclose a similar situation of only 87% of CT reports within the 2-day TAT target. Data from Public Health Scotland and Wales are not publicly available despite the author's Freedom of Information requests, although reporting delays impact outcomes have been cited (Wales Audit Office, 2018). The RCR (2016b, p.4) have stated, *"the human cost is patients are waiting more than a month for test results, often carried out to detect or monitor cancer. The cost to society will be patients with cancer in the UK continue to suffer worse outcomes due to late diagnosis*".

In response to the increasing delays in reporting, the RCR Workforce Quality and Efficiency Case (2012b, p.8) endorsed "*radiographers can now make a contribution to the reporting workload*", further echoed in the RCR workforce census (2019, p.41) that "*optimising skills mix is essential in seeking to increase efficiency in radiology services",* with radiographer reporting implemented in 84% of NHS trusts (RCR 2018a) and improved CT head reporting TATs (Woznitza, 2014). To meet demand, the diagnostic radiographer workforce has increased during the past decade by 27% (HCPC, 2016a; 2016b;

2017; 2019; SCoR, 2019) and is predicted to expand further with NHS England (2014c; 2017c) investment for an additional 2,845 radiographers by 2021. In England to support the increased demand in reporting, separate funding was provided by the NHS (2017d) to English universities to train 300 reporting radiographers (not specific to imaging modality) by 2020, with funding for another 376 reporting radiographers by 2021 (NHS People Plan, 2019a; NHS Long Term Plan, 2019b). The NHS Diagnostics Recovery and Renewal proposal (2020b) endorses further stakeholder funding for an additional 500 reporting radiographers to support the Community Screening Hub initiative to double CT imaging capacity in England. Similar initiatives in the devolved nations of Scotland (NHS Scotland, 2017) and Wales (Wales Audit Office, 2018) have supported increasing the radiographer reporting workforce, but no additional central funding has been allocated.

In summary, the ongoing CT reporting delays establish radiographers' opportunity (RCR, 2019; CQC, 2018; GIRFT, 2020) to reduce reporting TATs (Woznitza, 2014), improve patient outcomes in time-critical neurological conditions (NICE, 2020a; 2020b; NHS, 2019), and mitigate avoidable adverse events, length of stay in the hospital, and mortality due to delayed reporting.

1.3 Aims and objectives

This research programme aimed to investigate trained radiographers reporting CT head scans in the NHS:

- To assess the diagnostic efficacy (accuracy) of trained radiographers reporting CT head examinations.
- To assess the clinical utility of trained radiographers CT head reports (influence of report on the clinicians’ treatment and management plan to benefit patient outcomes).
- To determine the clinical validity (role within the patient pathway) and value (role within service delivery) of trained radiographers reporting CT head scans.
- To examine whether the trained radiographer CT head reporting role is cost-effective (monetary value impact) and cost-benefit (healthcare service delivery, and societal gain).

1.4 Ontology and epistemology

The direction and perspective (ontology) of the research topic was influenced by my academic role (overtly presented as a declaration of interest in each published paper in the annexe) and my previous clinical radiographer experience within CT imaging (service delivery and patient impact perspective) and accepts the implication of a radiographer background will have some inherent influence. However, it is a natural approach to explore and research topics within one's profession. But the impact of potential bias has been mitigated as much as reasonably possible by taking an objective approach to quantitative data analysis by checking data outcomes with co-authors and impartial academic programme internal and external examiner panels for verification and scrutiny, as well as an objective reporting stance of qualitative data (a balance of positive and negative participant data). The implication of a radiographer and academic background is also a strength in evidencing the impact of the research outcomes to academic and clinical stakeholders within conference and publication dissemination.

The ontological approach further acknowledged that reality continually changes in line with unpredictable 'real world' changes (Creswell, 2009) of variability in supply (workforce), demand (patient population) upon the NHS and the pressure to report to TAT standards.

As such this research was grounded in pragmatism for inquiry as a logical stance, acknowledging no single scientific method could capture all 'real world' answers (Johnson & Onwuegbuzie, 2004; Creswell, 2009; Sidiqui & Fitzgerald, 2014). Applying a Pragmatic paradigm as a theoretical lens on the assumptions of the nature of reality allowed the best opportunity to approach the research aims and objectives (Patton, 2002; Teddlie & Tashakkori, 2003).

The pragmatic paradigm focused the research method to a sequential empirical quantitative (studies 1 – 4) and mixed-method (studies 5 - 6) approach (Teddlie & Tashakkori, 2003; Johnson & Onwuegbuzie, 2004; Morgan, 2007; Creswell & Plano-Clark, 2011) to complement each step of the research (Cherryholmes, 1992; Patton, 2002; Creswell et al., 2003; Mackenzie & Knipe, 2006; Gray, 2009; Creswell, 2009). The pragmatic approach allowed deductive testing of theory (Fox et al., 2007) through quantitative research (internal and external validity) and inductive generation of theory (Mackenzie & Knipe, 2006; Grey, 2013) through exploratory qualitative research emphasising transferability and credibility to reach an understanding of the radiographer reporting role (Teddlie & Tashakkori, 2003; Johnson & Onwuegbuzie, 2004; Creswell, 2009; Creswell & Plano-Clark, 2011). Consequently, a combined study design of objective observational diagnostic accuracy (studies 1 - 4), exploratory cross-sectional implementation appraisal (studies 5 – 6), and economic evaluation (study 7) were applied to account for the subjective ontological experience of the social reality (Teddlie & Tashakkori, 2009; Fetters et al., 2013).

1.5 Research methodology

The NHS applies evidence-based research to determine risk to patients in order to ascertain effective treatment pathways and cost-effectiveness of interventions (Sackett et al., 1996; Munn, 2020; Brettle, 2020). In the appraisal process of any healthcare intervention, the most effective approach is a balanced framework that reduces bias, acknowledges when uncertainty is present in the data, and applies rigour and validity to the process. The Medical Research Council (MRC) likewise promotes a systematic approach in planning multifactorial evidence-based investigations and assessments in the development of advanced practice roles in healthcare (Craig et al., 2008). A pro-active approach, therefore, was to apply a framework analysis approach to manage and structure the research by use of coding, mapping and categorising the required steps of the research project (i.e. themes of efficacy, utility, validity, and economic impact) and identification of subtheme questions of technical accuracy, diagnostic accuracy, downstream clinical impact on decision making of treatment and management, multidisciplinary communication, adherence to professional role standards, and cost-effectiveness of the role).

Several hierarchical frameworks address healthcare evaluations of effectiveness, appropriateness, and feasibility (Evans, 2003), but ideally, a framework aligned to radiology with a logical progression was required. A literature review assessment was needed to justify the choice of efficacy framework to assess the intervention (CT head reporting by radiographers).

1.6 Approaches to identifying efficacy frameworks

The objective for undertaking this literature review was to establish which radiology-based efficacy framework would be sufficiently specific and sensitive for this purpose. The literature search of databases and subject-specific electronic publisher databases included:

- CINAHL (an electronic database of over 3,075 nursing and AHP journals).
- MEDLINE (a database of 26 million biomedicine articles indexed to MeSH subject headings).
- OVID (an online database of healthcare disciplines with 6,000 eBooks and 1,400 journals).
- PubMed (the US national library of medicine with over 6.4 million articles and 2,400 journals).
- ScienceDirect (medical publisher database of 12 million articles, 3,500 journals, 34,000 eBooks).
- Wiley Online (medical publisher database of 7.5million articles, 1,600 journals and 21,000eBooks).
- Google Scholar (the world’s largest academic search engine of full texts and metadata estimated 389 million articles).

The start date was set at 1950, as the first diagnostic accuracy study in radiology reporting was in 1949 (Garland, 1949). Keywords / search terms were developed through reading the literature, and Boolean operators (table 1) and inclusion/exclusion criteria (table 2) were applied to search for research studies, review articles and grey literature.

Databases	Keywords (Boolean Operators)	MeSh Terms
CINAHL MEDLINE OVID PubMed ScienceDirect Wiley Online Google Scholar	"Radiology Efficacy Framework*" AND "Radiology Hierarchical Model of Efficacy" OR "Radiology Efficacy Studies" Filters: Publication date from 1950/01/01 to present; English	Clinical Decision-Making; Analytic Hierarchy Process; Validation Study;

Table 1. Literature search terms relevant to efficacy frameworks in radiology.

Inclusion	Exclusion
Radiographer participation	Non-Radiology medical papers
CT head scans	Drug or Therapeutic studies
Reporting or Image Interpretation	Pharmacology or Genomic papers
Diagnostic accuracy	Artificial Intelligence or Machine learning studies
Diagnostic performance	
Diagnostic outcomes	Coronary and Cancer therapy studies
Clinical audits	
Empirical Research	
Narrative or Methodology reviews	
Grey Literature	

Table 2. Literature search inclusion and exclusion criteria applied to search results on efficacy frameworks in radiology.

1.7 Outcomes of the efficacy frameworks review

The literature review identified *n*=38 papers (reported in a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, 2009) flow chart, figure 2) debating and using efficacy framework studies in radiology. The seminal work of Ledley and Lusted (1959); Lusted (1968); Bell and Loop (1971); and Lusted (1971), formed the foundations of the American College of Radiologists' (ACR) Efficacy Studies Committee. The only use of an efficacy framework for CT head examinations was by the work of Fineburg (1977), whose study reviewed CT imaging introduction into hospitals. Fineburg (1977) observed technical output (image quality), diagnostic information (the report), the effect on the therapeutic plan (the clinician’s judgement), and the patient outcome (whether it improves). Further variations on frameworks evolved with the Institute of Medicine (1977), Fineburg (1978), Loop and Lusted (1978), and Guyatt et al. (1986a). The most cited and widely adopted efficacy framework was the Fryback and Thornbury (1991) model (figure 3). Although further variations specific for MRI imaging (Mackenzie & Dixon, 1995) and general healthcare (CDCP, 2010) have been published, the Fryback and Thornbury (1991) model continues to be applied in contemporary research (Brady et al., 2020).

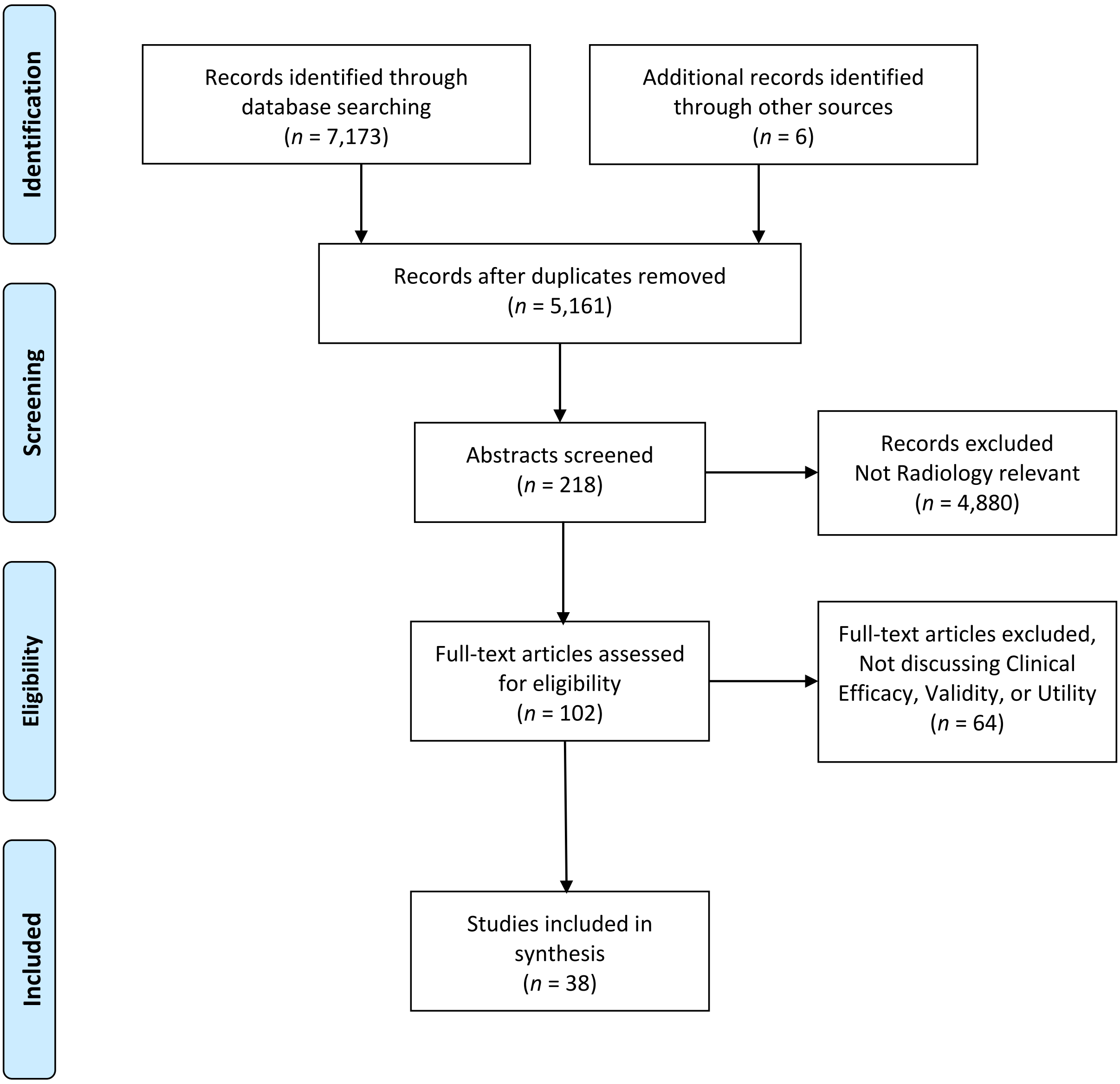
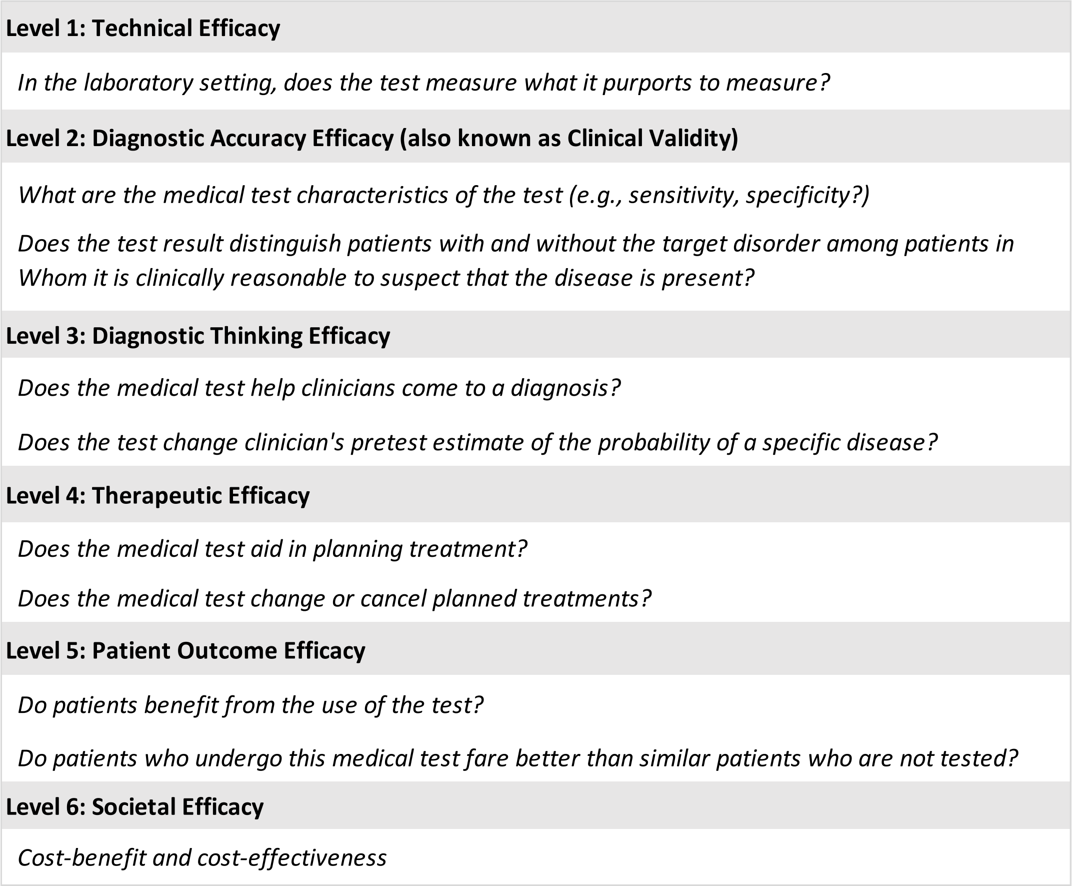


Figure 2. PRISMA (2009) flow diagram of the identified literature on efficacy studies in radiology.

The rationale for applying the Fryback and Thornbury (1991) framework (figure 3) as the approach for evaluating diagnostic tests is its validation in radiology reporting by Thornbury (1994); Dixon (1998); Pearl (1999); Jarvik (2001); Reed (2006); Sheehan et al. (2007); Sistrom (2009); Gazelle et al. (2011); Bossuyt et al. (2012); Seidel et al. (2016); Kostrubiak et al. (2018); and by Brealey (2001) in radiographer reporting.



Level 1: Technical Efficacy

In the laboratory setting, does the test measure what it purports to measure?

Level 2: Diagnostic Accuracy Efficacy (also known as Clinical Validity)

What are the medical test characteristics of the test (e.g., sensitivity, specificity?)

Does the test result distinguish patients with and without the target disorder among patients in Whom it is clinically reasonable to suspect that the disease is present?

Level 3: Diagnostic Thinking Efficacy

Does the medical test help clinicians come to a diagnosis?

Does the test change clinician's pretest estimate of the probability of a specific disease?

Level 4: Therapeutic Efficacy

Does the medical test aid in planning treatment?

Does the medical test change or cancel planned treatments?

Level 5: Patient Outcome Efficacy

Do patients benefit from the use of the test?

Do patients who undergo this medical test fare better than similar patients who are not tested?

Level 6: Societal Efficacy

Cost-benefit and cost-effectiveness

Figure 3. Fryback and Thornbury (1991) Hierarchical framework of efficacy.

The Fryback and Thornbury (1991) framework has professional endorsement by:

- The International Society for Strategic Studies in Radiology (Brady, 2020).
- The UK Royal College of Radiologists (2007b).
- The European Society of Radiology (Brady, 2020).
- The European Society of Paediatric Radiology (ESR, 2019).
- The American College of Radiologists (Lusted et al., 1980; Plevritis, 2005; Brady, 2020).
- The Radiological Society of North America (Brady, 2020).
- The Canadian Association of Radiologists (Norman et al., 1998; Brady, 2020).
- The Royal Australian and New Zealand College of Radiologists (Brady, 2020).
- The National Council on Radiation Protection and the American College of Physicians (Schwartz et al., 1982; Brook & Lohr, 1985).
- The Emergency Care Research Institute (ECRI, 2011).
- The Federal Co-ordinating Council for Comparative Effectiveness Research and the Patient-Centered Outcomes Research Institute (Gazelle et al., 2011).

The research methodology strength is that Thornbury (1994) advises the efficacy framework is adaptable to all diagnostic imaging and reporting. As such, it will be the golden thread applied to structure the research aims and objectives.

1.8 Use of Fryback and Thornbury framework to structure the research studies method

The Fryback and Thornbury (1991) framework (figure 3) starts at level 1 with 'technical efficacy' requiring empirical observational study to assess the baseline standards of education and training on radiographers reporting CT head cases (studies 1- 2; section 2) in a controlled academic environment. Brealey, Scally and Thomas (2002) classification of study design (table 3), justified by its subject relevance (radiography) and research related (reporting assessment) criteria, classify studies completed under exam conditions with robust reference standards in controlled conditions as ‘diagnostic accuracy’ studies, and the first of three important competencies to fulfil to evidence the reporting role.

Type	Description	Example
Diagnostic accuracy	To assess the film reading performance of one (or more) group of observers in controlled (ideal) conditions.	Radiographer's reporting on a validated bank of films as part of a postgraduate course.
Diagnostic performance	To assess the film reading performance of one group of observers during clinical practice.	An audit of radiographers' film reading performance.
Diagnostic outcome	To assess the film reading performance of two (or more) groups of observers during clinical practice.	A comparison of radiographers' and casualty officers' film reading performance.

Table 3. Classification of image reading studies (Brealey, Scally & Thomas, 2002).

Level 2 of the Fryback and Thornbury (1991) framework assesses reporting ability within clinical settings (studies 3 - 4; section 2). The aim was to evaluate any change in results in a clinical setting after a period of post-qualification experience. Brealey (2001) and Brealey, Scally and Thomas (2002) recommend two types of studies to achieve this goal ‘diagnostic performance’ (an audit of performance in clinical practice) and ‘diagnostic outcome’ (radiographer cohort in comparison to radiologist cohort in clinical practice for pragmatic effectiveness of performance that would affect patient outcomes). The decision to use observational case-controlled cohort study designs over prospective randomised clinical trial (RCT) study designs which are often considered the highest level of research evidence (Glover et al., 2006), was the degree of potential patient risk (delayed treatment and management) in acute traumatic brain injury (TBI) in prospective diagnostic outcome studies which would be unethical (Guyatt, 1986b; Blackmore & Cummings, 2004; Stolberg et al., 2004; Sistrom, 2009; di Ruffano et al., 2012; Korevaar et al., 2019).

Level 3 in the Fryback and Thornbury (1991) framework encompasses clinical utility assessment of the report effect on diagnostic thinking efficacy (of the referring clinician), i.e. communication within the skills mix of healthcare professionals involved in the patient pathway. This is a critical factor to establish as previously Donovan and Manning (2006, p.7) considered the role of radiographers reporting X-rays as merely '*task-specific or limited in scope'* that would not assist actionable clinical judgements by the clinician. Data collection through cross-sectional surveys (studies 5 - 6; section 2) investigated the CT head reporting radiographer's role in the NHS and the communication between the reporter (radiographer) and referring clinicians to evidence the relationship effect post-CT report on clinical decisions of patient treatment and management.

Level 4, therapeutic efficacy has previously been addressed by Loop and Lusted (1978), Fineburg (1978), Guyatt (1986a) and confirm CT as the optimum diagnostic pathway for neurological conditions (NICE, 2008a; 2008b; 2018a; 2019b; 2020a).

Level 5 patient outcome efficacy requires an estimation of the increased benefits to patients' management and treatment (outcomes) in acute time-critical neurological injuries (such as TBI and stroke) by increasing the workforce (implementing radiographer reporting) to reduce bottlenecks in CT report TATs. Longitudinal cross-sectional surveys on the role's implementation were ideal for achieving this objective (studies 5 - 6; section 2).

Level 6 assesses the reporting role through economic modelling to evaluate potential societal level cost savings. Brealey (2001) argues this step to be critical for stakeholders and policymakers to help determine if the reporting role is an efficient use of resources (cost-effective) and a cost-benefit to society, as the NHS is publicly funded with the vast majority derived from central taxation, (study 7, section 2).

In summary, this subsection provided both the research methodology and rationale of applying an efficacy framework to structure the research and the research study methods to achieve the thesis aims and objectives in a pragmatic approach.

1.9 Identifying the published evidence on CT head reporting by radiographers

The rationale for undertaking this review was to establish whether the literature around radiographers reporting CT head scans provides a valid and robust evidence base, specifically relating to reporting efficacy, utility, validity, and associated costs.

The literature search of databases and subject-specific electronic publisher databases applied the search approaches and databases/search engines system used in section 1.6 but with relevant search terms used (table 4). Inclusion criteria (table 5) applied a timescale set from 1995 (when radiographer reporting courses started in the UK) to the present time.

Databases	Keywords (Boolean Operators)	MeSh Terms
CINAHL MEDLINE OVID PubMed ScienceDirect Wiley Online Google Scholar	"CT head*" AND "Computed Tomography" OR "CT Brain" AND "Reporting Radiographer*" OR "Radiographer" OR "Diagnostic Radiographer" OR "Radiographer Reporting" OR "CT Head Reporting Radiographer" OR "Reporting Radiographer CT Head" OR "Radiographer Reporting CT Head" AND "Advanced Practitioner Radiographer" OR "Radiography Advanced Practice" Filters: Publication date from 1995/01/01 to present; English	Radiographic Image Interpretation; Tomography, X-Ray Computed; Radiography

Table 4. Literature search keywords relevant to CT head reporting by radiographers.

Inclusion	Exclusion
Radiographer participation	No Radiographer participation
CT head scans	Other Imaging modalities
Reporting or Image Interpretation	Grey Literature guidelines
Diagnostic accuracy	Grey Literature workforce reports
Diagnostic performance	Narrative reports or Case Studies
Diagnostic outcomes	
Clinical efficacy, validy or utility	
Clinical audits	
Downstream clinical outcomes	
Economic evaluation	
Clincial audits	
Empirical Research	

Table 5. Literature search inclusion and exclusion criteria.

The selection of critique frameworks to assess the articles identified from the search was undertaken applying the Enhancing the QUAlity and Transparency Of health Research (EQUATOR) Network guidance (University of Oxford, 2016). These recommended reporting guidelines are aligned to a pyramid hierarchy of research evidence (Glover et al. 2006) shown in figure 4. The key criteria in the choice of literature review frameworks were an assessment of the risk of bias and applicability concerns (quality and rigour) of each study and appraisal of any incomplete or inadequate reporting of the study as a further indicator of the quality, robustness, and scientific reproducibility.

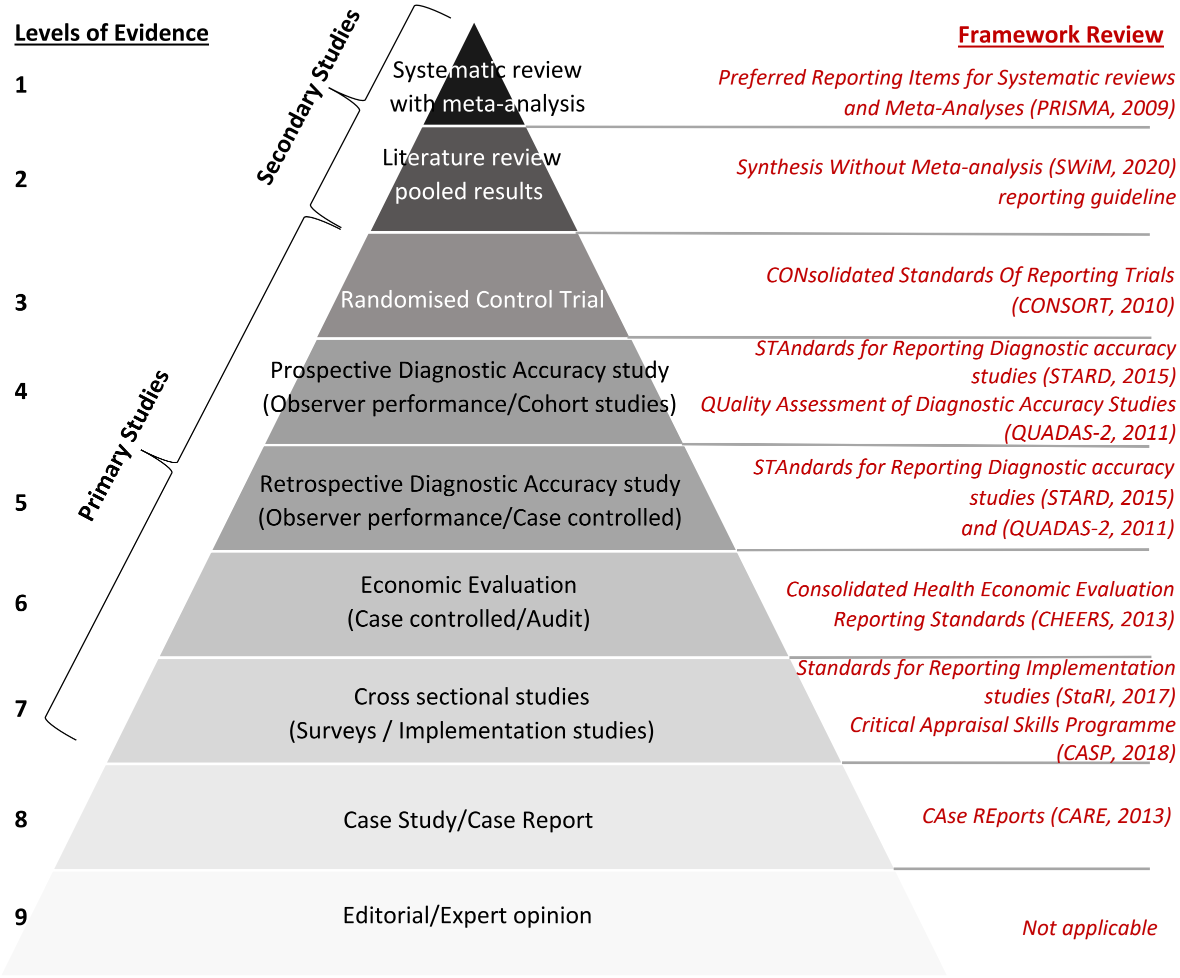


Figure 4. Hierarchy of evidence pyramid (adapted from Glover et al. 2006) and corresponding EQUATOR Network (2016) recommended reporting guidelines to review the evidence (on the right).

The justification for use of the QUality Assessment of Diagnostic Accuracy Studies (QUADAS-2, 2011) framework when assessing diagnostic accuracy (efficacy) studies (levels 4, 5; figure 4) are its recommendations by the Agency for Healthcare Research and Quality (AHRQ, 2008), Cochrane (2009), NICE (2012), Whiting et al. (2011); and Santaguida et al. (2012). The QUADAS-2 (2011) framework focuses on five critical areas of the method(s), which affects the generalisability of each study's findings (external validity):

- Sample size (both participants and patient caseload/disease conditions).
- Index test (CT head examinations).
- Reference standard (prior agreement of truth).
- Bias (risk rated as low, medium or high).
- Applicability (internal and external validity).

The second checklist applied to diagnostic accuracy (efficacy) studies (levels 4, 5; figure 4) is the STAndards for Reporting Diagnostic accuracy studies (STARD, 2015) checklist, focusing on the reported study's completeness and transparency (figure 4). This is different from QUADAS-2 (2011) in that the STARD (2015) checklist assesses for any omission or inadequate descriptions of essential methodological detail (Cochrane, 2009; Santaguida et al., 2012; Bossuyt et al., 2015). The STARD (2015) checklist calculates a numerical score (0=missing detail, 1= meets key criteria) of study quality against 34-items in categories of:

- Title
- Abstract
- Introduction
- Study design
- Participants
- Test Methods
- Analysis
- Results
- Discussion

For economic evaluation studies, the EQUATOR network (2016) recommends the Consolidated Health Economic Evaluation Reporting Standards (CHEERS, 2013) framework (figure 4) for the analysis of model-based evaluations (Husereau et al., 2013). The checklist was developed by the International Society for Pharmacoeconomics and Outcomes Research (Husereau et al., 2013) of 27-items to judge the quality and rigour of the study design and reporting against categories of:

- Title / Abstract
- Introduction
- Methods
- Results
- Discussion

For studies investigating the implementation of the role within clinical practice, the EQUATOR network (2016) recommends the Standards for Reporting Implementation studies (StaRI, 2017) checklist (figure 4). The StaRI (2017) checklist is validated for cross-sectional implementation studies to measure the study methods and reporting (Pinnock et al., 2017). The StaRI (2017) checklist involves numerical scoring against 27-item criteria on implementing the role and 10-item criteria of the intervention's impact to assess the potential for facilitating translation of the research into practice improvement of healthcare services against categories of:

Implementation Strategy

- Title / Abstract
- Introduction
- Methods Description
- Methods Evaluation
- Results
- Discussion
- General

Intervention Impact

- Rationale
- Methods Description
- Methods Evaluation
- Results
- Discussion

For published healthcare-related cross-sectional survey studies that do not focus on the implementation or impact of the role, the Critical Appraisal Skills Programme (CASP, 2018) checklist is recommended by the EQUATOR network (2016). The CASP (2018) checklist is a 12-item assessment with ratings (yes, no, can’t tell) and commentary boxes that appraise the study design and results and are endorsed by NICE (2018a) and Cochrane (2021) against categories of:

- Aims
- Methodology
- Recruitment
- Data collection
- Data analysis
- Findings

1.10 Findings on published studies on radiographer CT head reporting

The literature search results are presented in a PRISMA (2009) flow chart (figure 5) as recommended by the Cochrane Collaboration (2020) to document the different phases of the literature findings to identify, select and appraise the relevant papers.

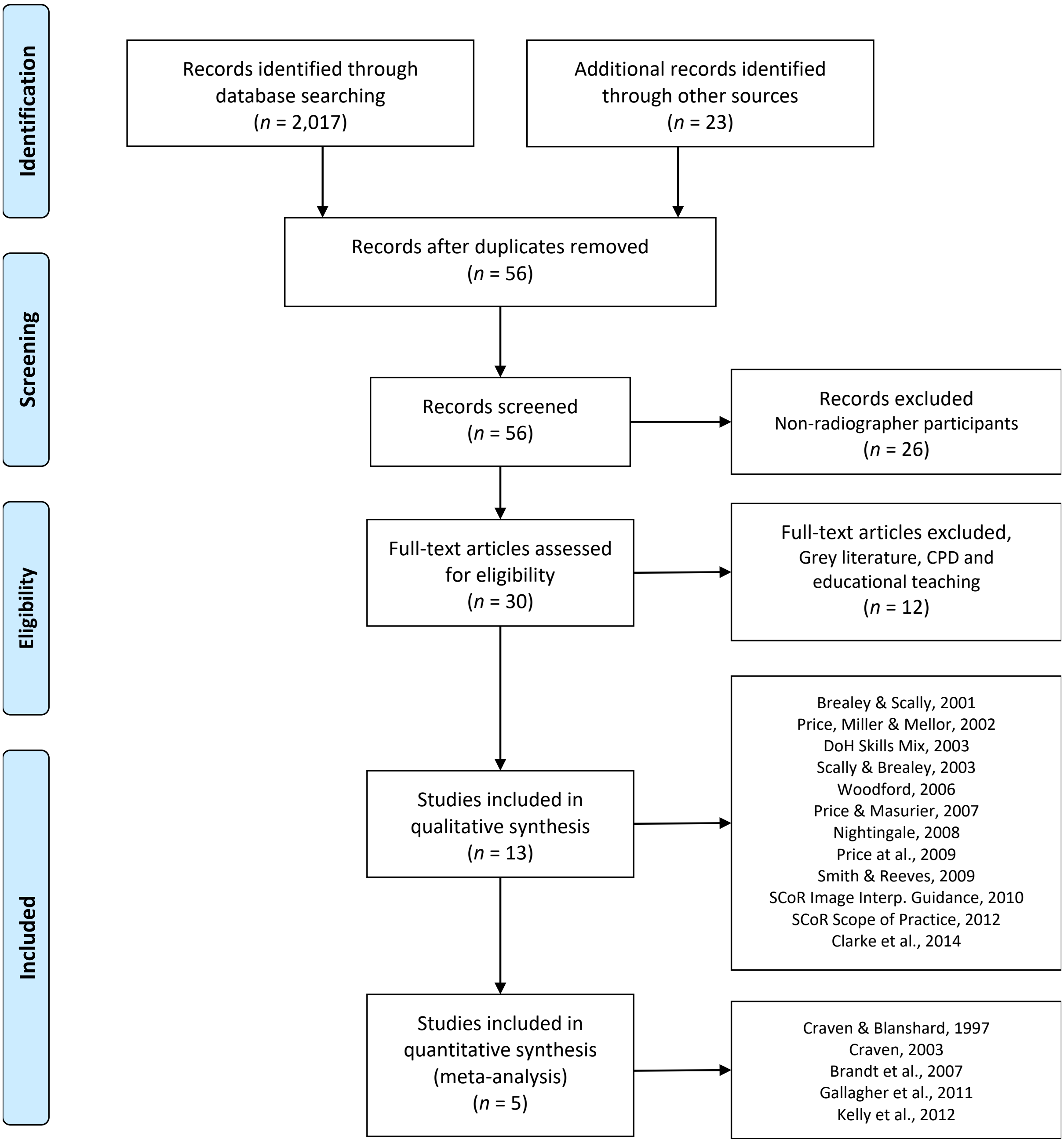


Figure 5. PRISMA (2009) flow chart of found published studies on radiographer CT head reporting.

The literature search identified (*n*=13) expert opinion articles from peer-review journals and grey literature which either cited (DoH, 2003; Woodford, 2006; Nightingale, 2008; Kelly, Piper & Nightingale, 2008) or critiqued (Brealey & Scally, 2001; Scally & Brealey, 2002,) research by Craven (1997; 2002). Other identified sources were case studies of radiographer CT head reporting within professional body guidance, such as the Radiography Skills Mix report (DoH, 2003), NHS Diagnosis and Stroke (2011a; 2011b), which constituted only summary, collation or synthesis of individual case studies, and as such were excluded (table 1.3.2).

Only one qualitative study was found comprising a cross-sectional survey on trainee CT head reporting radiographers and their NHS managers pre, during, and post-training (Clarke et al., 2014). The CASP (2018) review (figure 6) highlighted no concerns on study design or data analysis. The Clarke et al. (2014) study was important as it identifies issues on implementing the role post qualification that had not been identified in SCoR workforce reports (2012; 2019) of opposition from radiologists, delays in local policy implementation, or staff shortages to backfill duties as well as focusing on the benefits to service delivery and advanced radiographer practice of reporting CT heads.

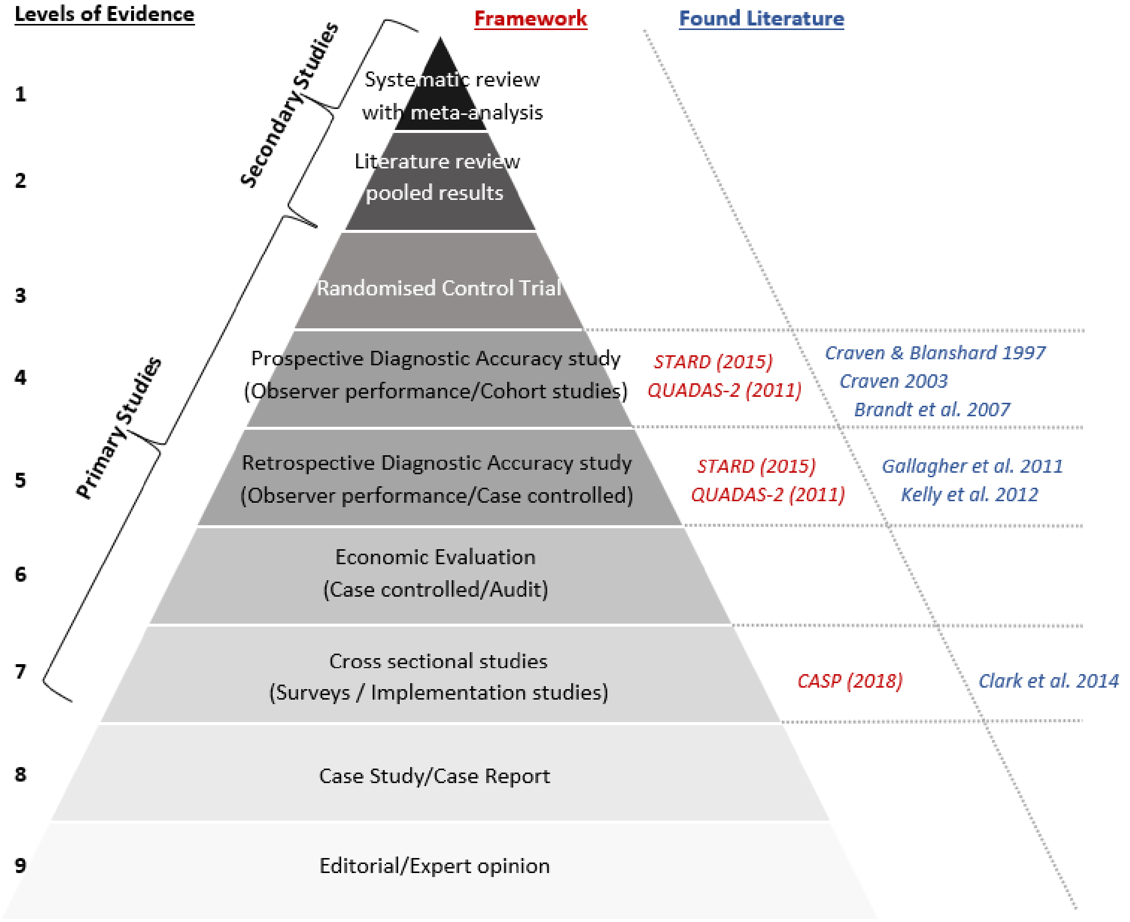


Figure 6. Hierarchy of evidence pyramid (adapted from Glover et al. 2006), corresponding to EQUATOR Network (2016) reporting guidelines (red), and the found literature (blue).

1.10.1 Diagnostic accuracy studies

The literature search did not identify any studies on radiographer CT head reporting accuracy within controlled academic environments which Brealey, Scally and Thomas (2002) state is the first of three important competencies (table 3) to fulfil to evidence the reporting role, and the basis of the first level of efficacy by Fryback and Thornberry (1991).

1.10.2 Diagnostic performance studies

Two studies were identified, the first (chronologically) consisted of a prospective audit by Craven (2003) of a radiographer (*n*=1) reporting printed film adult CT head scans published in a non-peer-review journal. It was unclear from the demographic details reported if the participant was a qualified reporting radiographer. The paper stated a further audit was completed in 6- and 12-months post-study, but outcome data was absent.

The second diagnostic performance study was a South African paper by Brandt et al. (2007) of radiographers (*n*=2) without training or qualifications in reporting. This task-based prospective study interpreted printed film paediatric CT head scans using a 7-point rating system. It was noted *n*=5 patient cases were lost in the analysis, which affected the statistical outcomes.

The QUADAS-2 (2011) risk of bias and applicability assessment (figure 4) of Craven (2003) and Brandt et al. (2007) identified patient filtering bias where no record of the criteria used to determine which CT cases were selected for the study. This resulted in biased population samples of adult patients (Craven, 2003) and paediatric patients (Brandt et al., 2000), which affect the applicability of the findings to 'real-world' patient referrals (tables 6 - 7).

The index test (CT head examinations) for both Craven (2003) and Brandt et al. (2007) identified bias of missing patient history and symptoms, which Brealey (2001) argues is a substantial disadvantage to the study participants decision making, which impacts the performance outcomes, and does not reflect real-world clinical practice thereby reducing the applicability of the results.

The reference standard applied in both Craven (2003) and Brandt et al. (2007) was subject to verification bias with the use of a single reader reference standard, which introduced inter-observer variation (bias) and single reader error bias (Brealey & Scally, 2001; Blackmore, 2001). Furthermore, arbitration bias was noted in the study designs that failed to incorporate independent ratification of agreement and concordance of results which is essential for rigour, data validity and applicability (Brealey & Scally, 2001).

The QUADAS-2 flow and timing of the study design, noted both Craven (2003) and Brandt et al. (2007) presented the CT images to the participants on printed film, reducing the participants' ability to manipulate the images (magnification, brightness, contrast, zoom, etc.), which did not reflect clinical reporting practice and raised applicability concerns. Furthermore, the Brandt et al. (2007) study used a normal/abnormal scoring system (pattern recognition task), not a written report. The timing details were missing from the study assessment; if participants took longer (exaggerate performance) or shorter (introducing errors) to review each case than routine clinical reporting practice, applicability bias would be present.

Study, Year	Method	Radiographer sample size	Qualified to report	Results	QUADAS-2 Score	Comments
Craven 2003	Single site study Prospective Audit *n* =252 Adult CT heads Printed hard copy film **Full report written**	*n* =1	**No**	99.4% Sens 98.5% Spec	High Risk of Bias	Sample criteria (*n* =252/4,400) missing (inclusion bias) Range/prevalence of disease unknown (disease bias) No history and symptoms (bias of information) Single reference standard (verification bias) No independent arbitration (verification bias) Reading environment missing (performance bias) Limited statistical analysis
Brandt et al., 2007	Single site study Prospective study *n* =95 Paed. CT heads Printed hard copy film **No report written** **Tick sheet scoring**	*n* =2	**No**	89.5% Acc 87-96% Sens 82-91% Spec	High Risk of Bias	Cases lost in study *n* =5/100 (bias of results) No history and symptoms (bias of information) Single reference standard (verification bias) No independent arbitration (verification bias) Reading environment missing (performance bias)

Table 6. The QUADAS-2 (2011) overall breakdown of Craven (2003) and Brandt et al. (2007) emphasising variance in study design, sample size, reference standards, and bias.

The Craven (2003) statistical analysis provided only sensitivity and specificity to justify the conclusions. Both studies provided no confidence intervals (95% CI) to identify the range of participant performance outside of the mean score, as argued for by Derry (1993) and Scally and Brealey (2003). Small sample sizes (table 6) of participants results in low power to detect statistical differences; thus, the *p*-values may also be misleading, reducing the validity of study outcomes and may over-interpret or 'spin' the findings (Ochodo et al., 2013; Bachmann et al., 2013). Both Craven (2003) and Brandt et al. (2007) are important studies as early attempts of diagnostic performance studies but suffer applicability concerns for evidence of radiographer 'reporting' ability (tables 6 -7).

Study, Year	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Craven 2003	High	High	High	Unclear	Unclear	Low	Low
Brandt et al., 2007	Low	High	High	Unclear	Low	Low	Low

Table 7. The QUADAS-2 (2011) risk of bias and applicability concerns for Craven (2003) and Brandt et al. (2007).

The STARD (2015) assessment (figure 4) for omission or inadequate descriptions of methodological detail identified the Brandt et al. (2007) study provided more detail in its study design than Craven (2003), which contained a limited method (table 8). The STARD (2015) assessment echoes the findings of the QUADAS-2 (2011) results, highlighting limited statistical analysis, resulting in a restricted discussion on the results and errors.

Section	Items	Craven 2003	Brandt et al., 2007
Title	1	0	1
Abstract	1	0	1
Introduction	2	2	2
Study design	1	1	1
Participants	4	4	4
Test Methods	7	0	6
Analysis	5	0	2
Results	8	1	5
Discussion	2	1	1
Other Info	3	0	0
Total Score	34	9	23

Table 8. The STARD (2015) reporting standard criteria scored the Brandt et al. (2007) diagnostic performance study higher than Craven (2003).

Both Craven (2003) and Brandt et al. (2007) diagnostic performance studies as classed by Brealey, Scally and Thomas (2002) (table 3) were important as an early published accounts of radiographer image interpretation ability of CT head scans.

1.10.3 Diagnostic outcome studies

Three studies of radiographer's performance assessed against another healthcare professional's performance (cohort vs cohort) were identified. The first (chronologically) was a single site prospective pilot study of printed adult CT head scans by Craven and Blanshard (1997), comparing a radiographer (*n*=1) against senior registrars (*n*=5) image reading. It was assumed that at the time of the study (February 1993), the participant was not a qualified reporting radiographer as the first reporting courses started in 1995.

The second study was a retrospective study by Gallagher et al. (2011) of a multi-site comparative cohort of medical and non-medical professions, including neuroradiographers (*n*=7) interpreting printed CT head scans (*n*=30). The participant scoring system used normal/abnormal and naming the abnormal conditions. The study involved a timed assessment of 1 hour for all (*n*=30) CT head scans, equating to 2 minutes per CT case which increased the potential to bias accuracy (Degnan et al. 2019). This was the only found study to contain a radiographer (*n*=1) with a CT head reporting qualification.

The third study was a single-site retrospective comparison study by Kelly et al. (2012) of radiographers (*n*=10) and junior doctors (*n*=10) interpreting CT head scans. Each CT head case was limited to a single midbrain printed image digitalised for electronic display (increasing the potential loss of image detail). The scoring system was annotation on the image of any abnormality and use of a 7-point rating system.

Each of the identified studies were assessed using QUADAS-2 (2011) for risk of bias and applicability (tables 9 – 10). Review of patient selection in the study design noted only Gallagher et al. (2011) had a mixed patient age range, Craven and Blanshard (1997) was biased to adult patients, Kelly et al. (2012) provided no patient demographics. The patient selection displayed a spectrum bias of limited disease prevalence in the Kelly et al. (2012) study, limiting the applicability of results to clinical practice. The index test (CT head scans) in the Craven and Blanshard (1997) and Gallagher et al. (2011) studies provided a range of cases reflecting clinical practice.

The QUADAS-2 (2011) review of reference standards in all three studies identified verification bias by applying single reader reference standards (Brealey & Scally, 2001; Blackmore, 2001) and arbitration bias (Brealey & Scally, 2001) through lack of independent ratification of agreement and concordance of results.

The QUADAS-2 (2011) flow and timing assessment of each study noted all three studies printed the CT images, which is not consistent with clinical reporting practice. Kelly et al. (2012) diminished applicability further with only images of midbrain anatomy. The reading room environment (including lighting) was not reported in the studies; this could impair performance (Brealey 2001) by not reflecting reporting environments. The time taken to interpret each case (flow and timing, table 10) introduced time-constrained bias, particularly in the Gallagher et al. (2011) study of 2 minutes per patient case. The Gallagher et al. (2011) and Kelly et al. (2012) studies were similar to the Brandt et al. (2007) study, which focused on assessing 'pattern recognition' abilities (scoring system of normal or abnormal) and not assessing written 'reporting' ability, thus reducing the applicability of the results.

The QUADAS-2 (2011) review highlighted limited statistical analysis with Craven and Blanshard (1997) providing of only mean sensitivity and specificity. Gallagher et al. (2011) displayed only cohort mean scores. When individual participant scores are not reported (observer variability bias), the studies fail to determine individual performance, thus reducing the range of ability and reliability of the data to evidence radiographer performance. Kelly et al. (2012) provided individual and mean accuracy scores, but omit inter-observer variability and CI were missing, reducing the ability to comprehend the range of scores.

Study, Year	**Method**	**Radiographer sample size**	**Qualified to report**	**Results**	**QUADAS-2 Score**	**Comments**
Craven and Blanshard 1997	Single site study Prospective Audit *n* =81 Adult CT heads Printed hard copy film History and symptoms **Full report written**	*n* =1	**No**	85.4% Sens 96.9% Spec	High Risk of Bias	Sample criteria (*n* =81/220) missing (inclusion bias) Range/prevalence of disease unknown (disease bias) Single reference standard (verification bias) No independent arbitration (verification bias) Reading environment missing (performance bias) Comparator *n* =5 registrars (1:5 cohort bias) Limited statistical analysis
Gallagher et al., 2011	Multi-site study Retrospective Study *n* =30 Mixed CT heads Printed hard copy film **No report written** **Limited commentary**	*n* =7	***n* =1**	23/30 (19.5-27.5)	High Risk of Bias	Sample criteria (*n* =252/4,400) missing (inclusion bias) Prevalence of disease unknown (disease bias) No history and symptoms (bias of information) Single reference standard (verification bias) No independent arbitration (verification bias) Reading environment missing (performance bias) Timed 2 minutes per case (performance bias) Limited statistical analysis
Kelly et al. 2012	Single site study Retrospective Study *n* =40 Mixed CT heads Hard copy film digitised **No report written** **7-point score provided**	*n* =10	**No**	0.70 AUC (0.61-0.80)	High Risk of Bias	Prevalence of disease limited (disease bias) Single mid brain image (performance bias) No history and symptoms (bias of information) Single reference standard (verification bias) No independent arbitration (verification bias) Reading environment missing (performance bias)

Table 9. The QUADAS-2 (2011) overall breakdown of Craven and Blanshard (1997), Gallagher et al. (2011), and Kelly et al. (2012) emphasising variance in study design, sample size, reference standards, and bias.

Study, Year	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Craven and Blanshard 1997	High	High	High	Unclear	Unclear	Low	Low
Gallagher et al., 2011	Low	High	Low	Low	Unclear	Low	Low
Kelly et al., 2012	High	High	High	Low	High	High	High

Table 10. The QUADAS-2 (2011) risk of bias and applicability concerns found the Gallagher et al. (2011) scored lower risk than Craven and Blanshard (1997) and Kelly et al. (2012) high risks of bias and concerns.

The STARD (2015) framework demonstrated all three diagnostic outcome studies had limited details on method, statistical analysis, and discussion of results (table 11) replicating the QUADAS-2 (2011) outcomes (tables 9 - 10).

Section	Items	Craven & Blanshard 1997	Gallagher et al., 2011	Kelly et al., 2012
Title	1	1	1	1
Abstract	1	1	1	1
Introduction	2	2	2	2
Study design	1	1	1	1
Participants	4	4	4	4
Test Methods	7	4	7	5
Analysis	5	2	3	2
Results	8	2	3	2
Discussion	2	2	1	2
Other Info	3	0	1	1
Total Score	34	19	24	21

Table 11. The STARD (2015) reporting standard score for the Gallagher et al. (2011) study was higher than Craven and Blanshard (1997) and Kelly et al. (2012).

The Craven and Blanshard (1997), Gallagher et al. (2011) and Kelly et al. (2012) diagnostic outcome studies as classed by Brealey, Scally and Thomas (2002) (table 3) are important early data alluding to radiographer interpretation ability of CT head scans in clinical environments.

1.10.4 Meta-analysis of results

Meta-analysis is performed when studies have recruited clinically similar patients and used comparable experimental methods and reference tests. From the quantitative studies (*n*=5), it was possible to construct contingency tables to calculate summary statistics and forest plots (figure 7 - 8) using Meta-DiSc v1.4 (Zamora, 2006) software. Forest plots display the area of each red dot as proportional to the study's weight; the overall measure of effect is represented as dashed vertical lines, with the pooled result as a diamond, the horizontal lines of each study indicate the CIs (the longer a line, the wider the CI) Leemis and Trivedi (1996). Summary pooled results of 84% sensitivity (95% CI 0.80-0.86) and 81% specificity (95% CI 0.77-0.84) indicated good ability to interpret CT head scans. The meta-analysis demonstrated a high degree of variability by the heterogeneity inconsistency (I^2) of 93.9%; and 95% (respectively). Some divergence in the heterogeneity (I^2) results is expected by chance (Higgins et al., 2002; 2003; 2008), the heterogeneity sources can be identified in the variations of the study designs of settings, populations, and disease prevalence (tables 6 - 11).

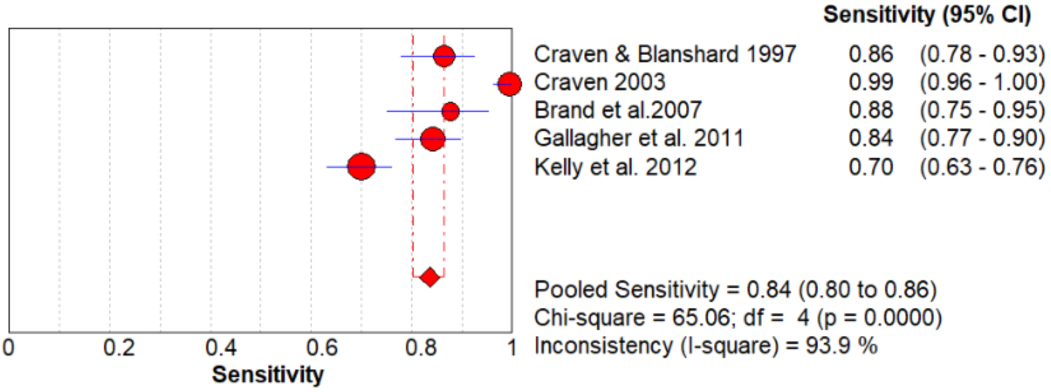


Figure 7. Forest plots meta-analysis demonstrating high overall sensitivity of 88% of published radiographer's performance indicated by the diamond (pooled effect) and dashed lines (CI).

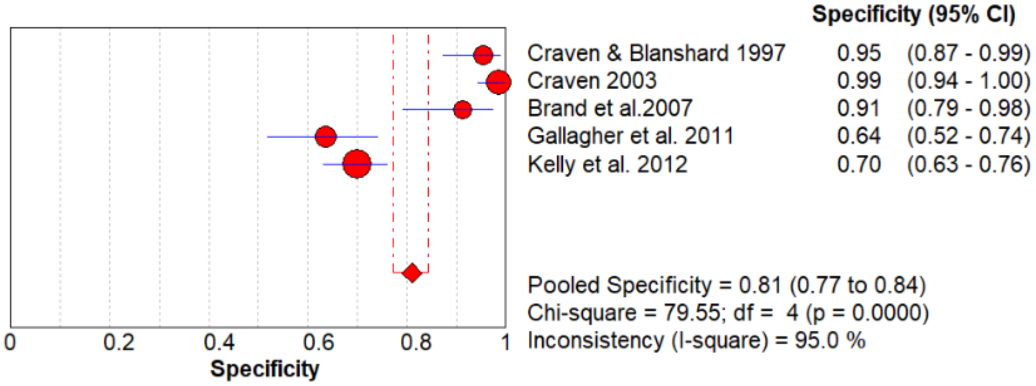


Figure 8. Forest plots meta-analysis demonstrating high overall specificity of 81% of published radiographer's performance indicated by the diamond (pooled effect) and dashed lines (CI).

The sensitivity and specificity can be plotted on a Receiver Operating Characteristic (ROC) plane (Swets & Pictett, 1982; Swets, 1988) to explore the effects of variation (I^2) upon the results. If threshold effects exist, they will show a curvilinear pattern on the ROC plot related to the underlying distribution of the combined studies test results. Summary ROC using Moses' Constant of Linear Model (weighted regression inverse variance) calculated the accuracy of radiographer's abilities (figure 9). A helpful statistic in pooling studies by ROC is the Area Under the Curve (AUC) which displays a summary of the diagnostic performance (Hanley & McNeil, 1982). The AUC is the most commonly used global measure of accuracy in diagnostic accuracy studies (Metz, 1978; Hanley & McNeil, 1982; 1983; Zweig & Campbell, 1993). Perfect scores have 1.0 AUC; a poor test will have 0.5 AUC (equivalent to 50/50 chance ability). The AUC is computed by numeric integration of the ROC curve equation by the trapezoid method (Zamora, 2006). Thus, 0.95 AUC indicates radiographers' ability to interpret CT head examinations is high. The standard error (SE) estimate of the sample means in distribution (i.e. how close the measurements of the same item are to each other), as a calculation of precision, was 0.04 SE(AUC). The Q* index statistic defines the point where sensitivity and specificity are equal in the found data (Walter, 2002); generally, the point closest to the top left corner of the ROC plot, the Q* index was 0.89 (SE 0.06), which demonstrated high ability.

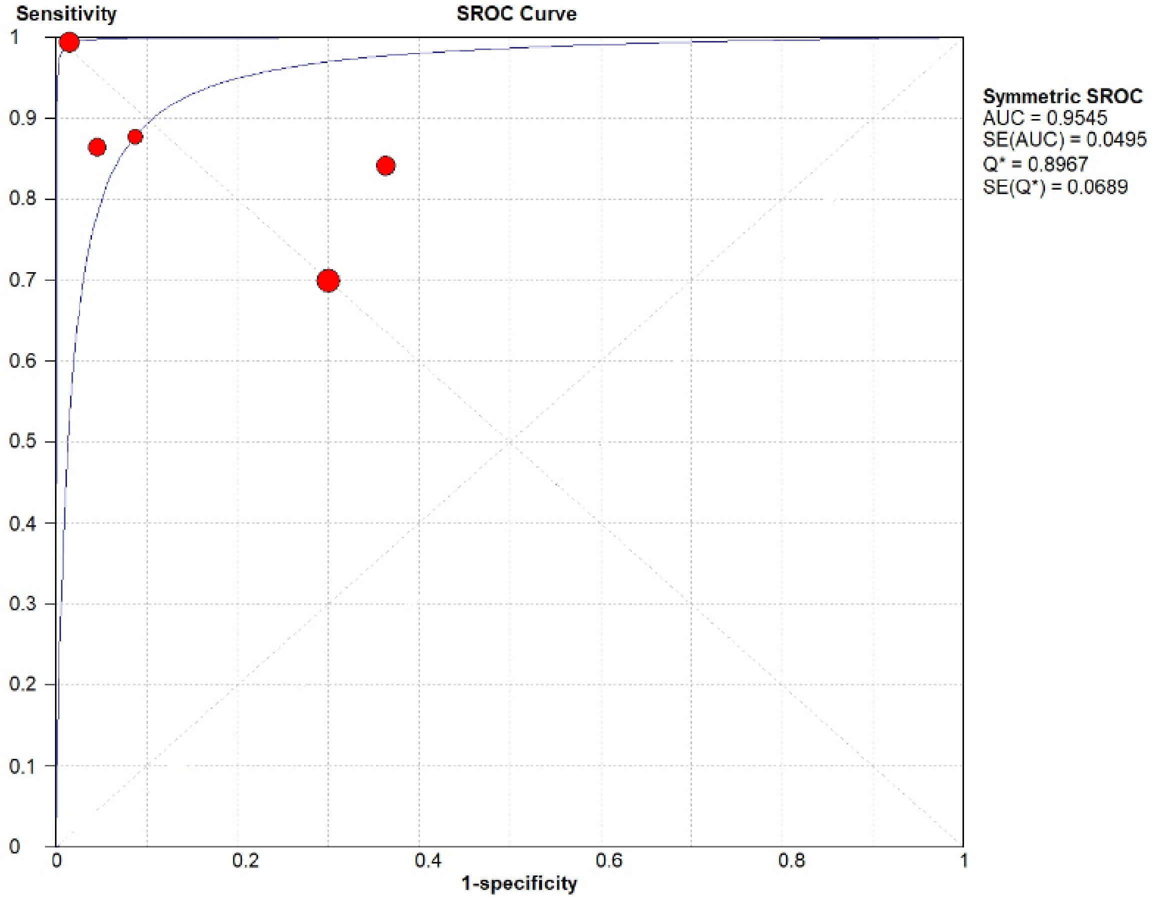


Figure 9. Summary ROC Curve meta-analysis of the published radiographer's accuracy in interpreting CT head scans.

1.11 Conclusion

The literature search of radiographers' ability to interpret and report CT head scans established limited data. The QUADAS-2 (2011) and STARD (2015) results were in general agreement, albeit they assessed different aspects of each study (risk of bias, applicability, and quality reporting). The methodological standards demonstrated wide variation, with reduced quality and rigour (e.g. low numbers of CT cases, small participant groups, lack of robust reference standards and limited statistical analysis). With *n*=3/5 studies assessing image interpretation (pattern recognition), scoring disease normal or abnormal, thus there was not enough published data to evidence radiographer's ability to report CT head scans.

Summarising the meta-analysis findings, the sensitivity, specificity, and ROC plot metrics scored high for image interpretation but displayed high heterogeneity within the studies (QUADAS-2, 2011 and STARD, 2015) results to be used for reporting ability. No published literature was identified on the impact or clinical influence downstream of the radiographer's reports on patient management or outcomes, and no economic analysis of the reporting role was found.

In conclusion, the literature review found *n*=5 studies demonstrated radiographer interpretation of CT heads scans to a high ability. However, bias was present in the study designs, and essential components of study quality were missing, which reduced the validity and applicability to underpin an evidence basis for reporting practice. Consequently, there is a 'knowledge gap' within the published literature on efficacy, clinical utility and validity, and economic evaluation of trained CT head reporting radiographers. Emerging from this literature review was the requirement for robust study design to address:

- Patient selection (range of disease and prevalence ratios).
- Patient history and symptoms (to replicate reporting and assess cognitive decision making).
- Participant sample size (to power statistical analysis).
- Replication of reporting environments and digital image display (to replicate reporting).
- Multiple reference standard (to reduce single reader error).
- Arbitration agreement (to validate findings).
- Detailed statistical analysis (to assess individual/cohort, range and variability)

These are important for study validity and trustworthiness, and in turn, essential for evidence on radiographer reporting that produces results that are translational to clinical practice.

2.0 Critical appraisal and reflective commentary on submitted studies

This section includes a critical appraisal of the seven research outputs submitted within this thesis undertaken using the same critique frameworks as described in section 1 (figure 10). The order of studies is presented following Fryback and Thornbury's (1991) efficacy framework (figure 11), concluding with a meta-analysis undertaken to systematically assesses the results of studies 1 - 4. Contributions of the author and co-authors for each study are confirmed in appendix 2. Study 1 was written during the last cohort of students in the study in 2015 who consented in person. Previous cohort students were individually contacted for informed consent, and institutional ethical approval was given for the use of retrospective examination data. Studies 2 – 4 recruited and consented different participants in person for each study. Studies 5 - 6 consented participants online, and study 7 gained institutional ethical approval for retrospective audit data. At the time of the study, the NHS Health Research Authority (2017) decision tool classified the study as a service evaluation audit that did not require full NHS Research Ethics Committee application. All ethical approvals are provided in appendix 3.

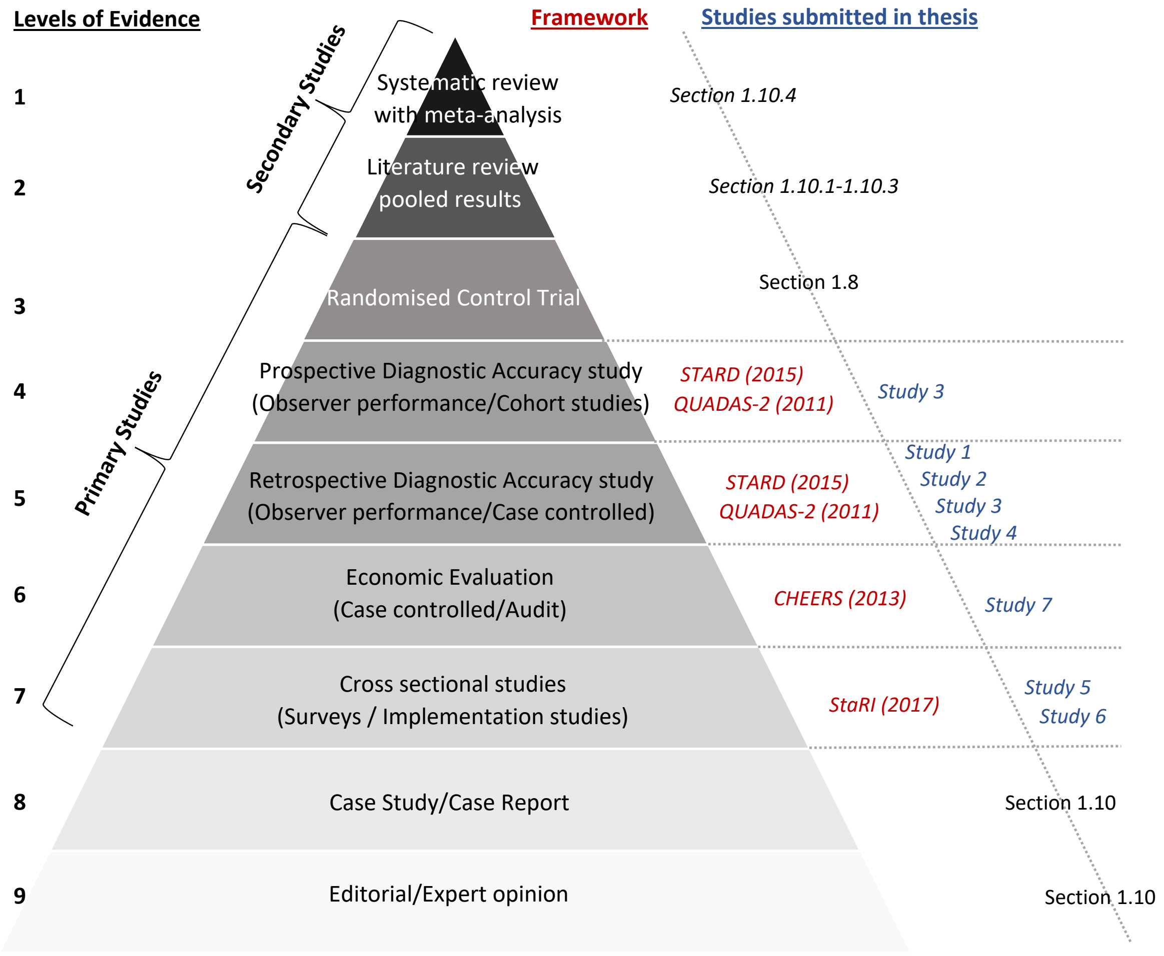


Figure 10. Hierarchy of evidence pyramid (adapted from Glover et al. 2006), corresponding to EQUATOR Network (2016) reporting guidelines (red), and the submitted studies (blue).

Level 1: Technical Efficacy

In the laboratory setting, does the test measure what it purports to measure?

Study 1 - Lockwood, P., Piper, K., Pittock, L. (2015) 'CT head reporting by radiographers: Results of an accredited postgraduate programme', *Radiography* , 21(3), pp. e85-e89.

Study 2 - Lockwood, P. (2017) 'CT sinus and facial bones reporting by radiographers: findings of an accredited postgraduate programme', *Dentomaxillofacial Radiology* , 46(5), 20160440, pp.1-11.

Level 2: Diagnostic Accuracy Efficacy (also known as Clinical Validity)

What are the medical test characteristics of the test (e.g., sensitivity, specificity?)

Does the test result distinguish patients with and without the target disorder among patients in
Whom it is clinically reasonable to suspect that the disease is present?

Study 3 - Lockwood, P. (2017) 'Observer performance in Computed Tomography head reporting', *Journal of Medical Imaging and Radiation Sciences* , 48(1), pp. 22-29.

Study 4 - Lockwood, P., Piper, K. (2015) 'AFROC analysis of reporting radiographer's performance in CT head interpretation', *Radiography* , 21(3), pp. e90-e95.

Level 3: Diagnostic Thinking Efficacy

Does the medical test help clinicians come to a diagnosis?

Does the test change clinician's pretest estimate of the probability of a specific disease?

Study 5 - Lockwood, P. (2017) 'Exploring variation and trends in adherence to national occupational standards for reporting radiographers', *Journal of Social Science and Allied Health Professions* , 1(1), pp. 20-27.

Study 6 - Lockwood, P. (2020) 'An evaluation of CT head reporting radiographers' scope of practice within the United Kingdom', *Radiography* , 26(2), pp. 102-109.

Level 4: Therapeutic Efficacy

Does the medical test aid in planning treatment?

Does the medical test change or cancel planned treatments?

Study 5 - Lockwood, P. (2017) 'Exploring variation and trends in adherence to national occupational standards for reporting radiographers', *Journal of Social Science and Allied Health Professions* , 1(1), pp. 20-27.

Study 6 - Lockwood, P. (2020) 'An evaluation of CT head reporting radiographers' scope of practice within the United Kingdom', *Radiography* , 26(2), pp. 102-109.

Level 5: Patient Outcome Efficacy

Do patients benefit from the use of the test?

Do patients who undergo this medical test fare better than similar patients who are not tested?

Study 5 - Lockwood, P. (2017) 'Exploring variation and trends in adherence to national occupational standards for reporting radiographers', *Journal of Social Science and Allied Health Professions* , 1(1), pp. 20-27.

Study 6 - Lockwood, P. (2020) 'An evaluation of CT head reporting radiographers' scope of practice within the United Kingdom', *Radiography* , 26(2), pp. 102-109.

Level 6: Societal Efficacy

Cost-benefit and cost-effectiveness

Study 7 - Lockwood, P. (2016) 'An economic evaluation of introducing a skills mix approach to CT head reporting in clinical practice', *Radiography* , 22(2), pp. 124-130.

Figure 11. The studies (1 – 7) are presented aligned to the efficacy framework of Fryback and Thornbury (1991).

2.1 Study 1

Lockwood, P., Piper, K., Pittock, L. (2015) ‘CT head reporting by radiographers: Results of an accredited postgraduate programme’, *Radiography*, 21(3), pp. e85-e89.

This quantitative quasi-experimental multi-reader multi-case (MRMC) observer performance study commenced data collection in 2014. At publication in August 2015, the empirical research was original and novel in being the first and the only to date of radiographer CT head reporting diagnostic accuracy (as defined by Brealey, Scally & Thomas, 2002) to assess level 1 of Fryback and Thornbury’s (1991) efficacy framework (figure 11).

The retrospective study of adult CT head examinations (appendix 4) included a wide range of pathologies as recommended by Brealey (2001) and Brealey and Scally (2001) to quality assure the participants' ability over a range of disease level and types. The study applied a disease prevalence ratio of 1:1 to reduce spectrum bias of disease and overestimation bias (Ransohoff & Feinstein, 1978). The reference standard applied the rigour of three independent and blinded (to each other’s reports) consultant radiologists. Brealey et al. (2001; 2002; 2005) recommends three as the benchmark to reduce single reader error bias and an adjudication panel (Sackett et al., 1991; White et al., 1994) of reporting radiographers and an independent consultant radiologist for review of errors.

The radiographer participants were provided with full referral details to improve metacognition and reduce information bias, as advised by Brealey (2001). Obuchowski (2004) would class this study as a Phase I exploratory assessment of the diagnostic accuracy of a small sample of patients.

The radiographers were assessed at the end of education and training in laboratory settings to control the environment (lighting, sound, time, and interruptions). The radiographers wrote free text full radiology reports, which allowed assessment of any type 1 or 2 cognitive, heuristic and perceptual decision-making errors found in reporting practice (Busby et al., 2018), as well as the clarity, brevity, and clinical correlation of the written report, as a metric of the quality of the report to communicate its findings to a clinician.

The statistical analysis applied standard Bayes theorem models of agreement and discriminating power as measured with sensitivity and specificity as recommended by Yerushalmy (1947); Chang (1989); Reitsma et al. (2005); and Anvari et al. (2015).

The RCR and NHS provide no nationally defined benchmark of diagnostic accuracy in CT head reporting. A literature search produced a range of radiologist CT head efficacy levels fluctuating from 66 – 97.3% (Schriger et al., 1998; Erly et al., 2003; Le et al., 2007; Briggs et al., 2008; Nagaraja et al., 2009; McCarron et al., 2010), the mean radiologist accuracy was 85.5%. The study outcome results for the trained reporting radiographers were significant, with an agreement score of 90.6% (95% CI 0.88-0.91) for level 1 technical efficacy (Fryback & Thornbury, 1991).

Critical appraisal using the QUADAS-2 (2011) framework evidenced the study design had a low risk of bias and demonstrated quality, rigour, and high standards, which reduced applicability concerns regarding the patient sample (range of age and abnormalities), the reference standard (index test), and timing and flow (tables 12 - 13). The STARD (2015) critical appraisal for the reporting of the study (table 14) indicated the method were described comprehensively. There were no identified issues in the validity of the method or interpretation of findings. The STARD (2015) checklist (table 14) highlighted radiography peer-review journals do not routinely publish study flow charts (1 point in the 'result' section, flow chart shown in appendix 5) or study protocols (1 point in the 'other information' section). Additionally, the study was not funded but did not disclose this in the publication, losing a further point from the score. The final score was 31/34, indicating high standards in reporting the study design, method, and analysis.

Study, Year	**Method**	**Radiographer sample size**	**Qualified to report**	**Results**	**QUADAS-2 Score**	**Comments**
Study 1 : Lockwood, Piper, Pittock, 2015	Single site study Retrospective study *n* =25 Adult CT heads PACs reporting monitor History and symptoms **Full report written**	***n* =24**	***n* =24**	90.6% Agree 99.4% Sens 95.9% Sepc	Low Risk of Bias	Range/prevalence of disease provided Three independent reference standards Independent arbitration panel Reading environment detailed Full statistical analysis

Table 12. The QUADAS-2 (2011) overall study 1 methods in terms of patients, index test, reference standard and target condition.

Study, Year	**Risk of Bias**				**Applicability Concerns**		
	Patient Selection	**Index Test**	**Reference Standard**	**Flow and Timing**	**Patient Selection**	**Index Test**	**Reference Standard**
Study 1 : Lockwood, Piper, Pittock, 2015	Low	Low	Low	Low	Low	Low	Low

Table 13. The QUADAS-2 (2011) risk of bias and applicability concerns appraisal of study 1.

Section	**Items**	*Study 1* **Lockwood, Piper, Pittock 2015**
Title	1	1
Abstract	1	1
Introduction	2	2
Study design	1	1
Participants	4	4
Test Methods	7	7
Analysis	5	5
Results	8	7
Discussion	2	2
Other Info	3	1
Total Score	34	31

Table 14. The STARD (2015) score of study 1.

2.2 Study 2

Lockwood, P. (2017) 'CT sinus and facial bones reporting by radiographers: findings of an accredited postgraduate programme', ***Dentomaxillofacial Radiology*****, 46(5), 20160440, pp.1-11.**

This quantitative quasi-experimental MRMC observer performance study commenced data collection in 2016. At publication in August 2017, this empirical research was unique in being the first nationally and internationally on trained radiographer CT sinus and facial bone reporting diagnostic accuracy (appendix 5) in a controlled academic environment (Brealey, Scally & Thomas, 2002). This work progressed the CT head reporting of pathology that extends into the craniofacial anatomy and aligned to level 1 of Fryback and Thornbury's (1991) efficacy framework (figure 11).

This retrospective Phase I exploratory study (Obuchowski, 2004) applied a disease prevalence of 52%. The comparator reference standard applied three consultant radiologists independent and blinded to each report (Lijmer et al., 1999; Reitsma et al., 2009). Concordance of data analysis was completed by an arbitration panel of reporting radiographers and consultant radiologists (Sackett et al., 1991; White et al., 1994). Internal validity was confirmed with the radiographer blinded to the reference standard and external validity of the research design reflecting the target population (Eng & Siegelman, 1997). As there is no RCR or NHS benchmark of radiologist efficacy, a literature review of radiologist's reporting CT sinus and facial bones examinations provided a summary of an additional comparator for the radiographer's performance.

The study applied statistical analysis of accuracy, sensitivity, specificity, and AUC. Cohen's Kappa (*K*) statistical measure of chance agreement (Bland & Altman, 1986), Fliess' *K* for multiple reader reliability agreements (Gonen et al., 2001; Brealey & Scally, 2001) with Fishers Exact Test for statistical significance in small samples (Anvari, 2015), and the effects of variables using positive and negative predictive values to evaluate influence by disease prevalence. Likelihood Ratios (LR) and Diagnostic Odds Ratios (DOR) assessed performance, not disease prevalence dependent, but reliant on the spectrum of conditions (Blackmore & Cummings, 2004). The results established a high level of accuracy equitable to consultant radiologist's for Fryback and Thornbury (1991) level 1 technical efficacy.

Critical appraisal using the QUADAS-2 (2011) framework evidenced the study design had a low risk of bias which reduced applicability concerns (tables 15 - 16). The STARD (2015) critical appraisal of the study's reporting (table 17) identified no issues in the validity of the method or interpretation of findings. The STARD (2015) checklist (table 17) noted no published study flow chart (1 point deducted, flow chart in appendix 5), or study protocols (1 point deducted); the final score 32/34 indicated high standards in reporting of the study design method, and analysis.

Study, Year	Method	Radiographer sample size	Qualified to report	Results	QUADAS-2 Score	Comments
Study 2 : Lockwood 2017	Single site study Retrospective study *n* =25 Adult CT Sinus/Facial CTs PACs reporting monitor History and symptoms **Full report written**	***n* =6**	***n* =6**	0.98 AUC 95.0% Acc 97.5% Sens 93.6% Spec	Low Risk of Bias	Range/prevalence of disease provided Three independent reference standards Independent arbitration panel Reading environment detailed Full statistical analysis

Table 15. The QUADAS-2 (2011) overall study 2 methods in terms of patients, index test, reference standard and target condition.

Study, Year	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Study 2 : Lockwood 2017	Low	Low	Low	Low	Low	Low	Low

Table 16. The QUADAS-2 (2011) risk of bias and applicability concerns appraisal of study 2.

Section	Items	*Study 2* Lockwood 2017
Title	1	1
Abstract	1	1
Introduction	2	2
Study design	1	1
Participants	4	4
Test Methods	7	7
Analysis	5	5
Results	8	7
Discussion	2	2
Other Info	3	2
Total Score	34	32

Table 17. The STARD (2015) score of study 2.

2.3 Study 3

Lockwood, P. (2017) 'Observer performance in Computed Tomography head reporting', *Journal of Medical Imaging and Radiation Sciences*, 48(1), pp. 22-29.

This quantitative quasi-experimental MRMC observer performance study commenced data collection in 2016. At the time of publication in March 2017, the empirical research was original in being the first and only to date of trained reporting radiographer CT head diagnostic accuracy in a controlled academic environment (retrospective assessment) and diagnostic performance (prospective workload audit) in a clinical setting (appendix 6) as defined by Brealey (2001), and Brealey, Scally and Thomas (2002) aligning to level 2 of Fryback and Thornbury's (1991) efficacy framework (figure 11).

The samples used for the retrospective study included multiple case-controlled CT head examinations with a disease prevalence ratio of 1:1 normal/abnormal, covering a range of pathology to reduce spectrum bias. The retrospective study is classed by Obuchowski (2004) as a Phase II challenge of difficult cases containing single and multiple, subtle and typical pathology.

The prospective study disease prevalence ratio was 42-46%, which was similar to Hardy et al. (2015) prospective workload disease prevalence ratios for trained reporting radiographers' assessment. Obuchowski (2004) defines the prospective study as a Phase III advanced study as it incorporated multiple observers, multiple institutions, and large prospective caseload assessment.

The rigour of using a pragmatic approach of real-world clinical reporting settings and equipment that adhered to SCoR (2013) and RCR (2011; 2012c; 2013) reporting standards and replicated clinical audit practice guidance recommended at the time by the RCR (2006) increased the validity of the study design (Obuchowski & Zepp, 1996; Blackmore, 2001).

The comparator reference standard applied three independent consultant radiologists blinded to each other's reports, with a concordance arbitration panel as recommended by Brealey (2001); Brealey and Scally (2008); Brealey, Scally and Thomas (2002); and Reitsma et al. (2009).

The statistical analysis identified individual reader and mean overall outcome scores (Obuchowski & Lieber, 2008). With Cohen's *K* and Analysis of Variance (ANOVA) to assess the differences among the group (inter-reader variability).

The prospective clinical assessment of CT cases was equivalent to sample size calculations for reading performance by Scally and Brealey (2003). The results exceeded the Scally and Brealey (2003) target outcome of 80% sensitivity and were comparable to the 95% specificity target.

In summary, study 3 findings built upon the 'diagnostic accuracy' results of studies 1 – 2 and confirm high 'diagnostic accuracy' in controlled academic environments (as defined by Brealey, Scally &

Thomas, 2002) and high ‘diagnostic performance’ (as defined by Brealey, Scally & Thomas, 2002) in prospective clinical settings for levels 1 and 2 efficacy of the Fryback and Thornbury (1991) framework.

Critical appraisal of study 3 by QUADAS-2 (2011) criteria for methodological rigour, patient sample, reference standard, and timing and flow (Appendix 6) identified a low risk of bias (tables 18 - 19), with applicability of patient samples and reference standards to ‘real-world’ clinical practice summarised no concerns. The assessment against the STARD (2015) framework for the reporting of the data demonstrated a high score (31/34), confirming the validity of reporting of the study. The points deducted against the STARD (2015) criteria (table 20) were due to the study flow chart not published (1 point), study protocols (1 point), and no disclosure that the study was not funded (1 point).

Study, Year	Method	Radiographer sample size	Qualified to report	Results	QUADAS-2 Score	Comments
Study 3 : Lockwood 2017	Multi-site study *n* =5 Prospective study *n* =738 Mixed CT heads Retrospective study *n* =2,270 Mixed CT heads PACs monitor History and symptoms **Full report written**	***n* =6**	***n* =6**	90.7% Acc 86.9% Sens 94.0% Spec	Low Risk of Bias	Range/prevalence of disease provided Three independent reference standards Independent arbitration panel Reading environment detailed Full statistical analysis

Table 18. The QUADAS-2 (2011) overall study 3 methods in terms of patients, index test, reference standard and target condition.

Study, Year	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Study 3 : Lockwood 2017	Low	Low	Low	Low	Low	Low	Low

Table 19. The QUADAS-2 (2011) risk of bias and applicability concerns appraisal of study 3.

Section	Items	*Study 3* Lockwood 2017
Title	1	1
Abstract	1	1
Introduction	2	2
Study design	1	1
Participants	4	4
Test Methods	7	7
Analysis	5	5
Results	8	7
Discussion	2	2
Other Info	3	1
Total Score	34	31

Table 20. The STARD (2015) score of study 3.

2.4 Study 4

Lockwood, P., Piper, K. (2015) 'AFROC analysis of reporting radiographer's performance in CT head interpretation', *Radiography*, 21(3), pp. e90-e95.

This quantitative quasi-experimental MRMC multi-site 'diagnostic outcome' cohort study in a clinical reporting setting (Brealey, Scally & Thomas, 2002), aligning to level 2 of Fryback and Thornbury's (1991) efficacy framework (figure 11).

The study used retrospective disease prevalence controlled CT head examinations (appendix 7). Brealey (2001) advises a wide range and variance in types of patients and conditions (as used previously in studies 1 - 3), with a sufficiently powered sample size (participants) to validate trained radiographers' diagnostic outcomes for meaningful results. The study used Obuchowski (2000) sample size tables for MRMC observer performance using ROC methodology. The radiographer cohort consisted of n=6 qualified (n=1-10 years) CT head reporting radiographers, the comparator cohort recruited n=6 consultant radiologists from n=6 NHS hospitals (rigour of independence and range of clinical practice). On the day of assessment, only n=2/6 radiologists attended, reducing the cohort sample (under-powered); potentially, a small interobserver accuracy difference may have occurred with the additional radiologists' data.

The study used Obuchowski (2000) case sample size calculations using 5% type 1 error and 80% power and conjectured radiologist accuracy from study 1. The disease prevalence ratio was 1:1 as a balanced approach endorsed by Metz (1978); Obuchowski (2000); Brealey (2001); Pepe (2003), Brealey and Scally (2008).

The reference standard used multiple independent consultant radiologists blinded to each report to reduce verification bias (Obuchowski & Lieber, 2008). Concordance of the resulting definitive reference standard was completed by panel arbitration as recommended by Brealey and Scally (2001) and Brealey, Scally and Thomas (2002) for the rigour of methodological standards.

The statistical analysis applied Alternative Free-response Receiver Operating Characteristic (AFROC) to distinguish statistical differences for the number of abnormalities (multiple and single lesions), as well as the location (region of interest defined), ranked against a confidence scoring system (Metz, 1978; Thornbury, 1994; Chakraborty, 2002). Full written free text reports recording the diagnosis and descriptive characteristics were also included.

In summary, the outcomes between radiographers and radiologists resulted in a <0.05 AUC of inter and intraobserver level of variability to evidence level 2 of the Fryback and Thornbury (1991) framework. Critical appraisal of the research by QUADAS-2 (2011) criteria (tables 21 - 22) identified a low risk of bias in the methodological quality. The STARD (2015) framework (table 23) demonstrated a high score (32/34) with deductions for the non-published study flow chart (1 point) and study protocol (1 point).

Study, Year	Method	Radiographer sample size	Qualified to report	Results	QUADAS-2 Score	Comments
Study 4 : Lockwood and Piper, 2015	Multi-site study *n* =6 Retrospective study *n* =30 Adult CT heads PACs reporting monitor History and symptoms **Full report written**	***n* =6**	***n* =6**	0.97 AUC 92.2% Acc 88.7% Sens 95.6% Spec	Low Risk of Bias	Range/prevalence of disease provided Three independent reference standards Independent arbitration panel Reading environment detailed Full statistical analysis

Table 21. The QUADAS-2 (2011) overall study 4 methods in terms of patients, index test, reference standard and target condition.

Study, Year	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Study 4 : Lockwood and Piper 2015	Low	Low	Low	Low	Low	Low	Low

Table 22. The QUADAS-2 (2011) risk of bias and applicability concerns appraisal of study 4.

Section	Items	*Study 4* Lockwood & Piper 2015
Title	1	1
Abstract	1	1
Introduction	2	2
Study design	1	1
Participants	4	4
Test Methods	7	7
Analysis	5	5
Results	8	7
Discussion	2	2
Other Info	3	2
Total Score	34	32

Table 23. The STARD (2015) score of study 4.

2.5 Study 5

Lockwood, P. (2017) 'Exploring variation and trends in adherence to national occupational standards for reporting radiographers', *Journal of Social Science and Allied Health Professions*, 1(1), pp. 20-27.

This mixed-method cross-sectional survey commenced data collection in 2015, and aligned to level 3, 4 and 5 of Fryback and Thornbury's (1991) framework (figure 11). The research presented novel and previously unexplored findings that addressed role implementation within NHS clinical practice and variations of adherence to professional guidance. Allowing comparison of the implementation of CT head reporting role in clinical practice to the implementation of X-ray reporting from census surveys (Price et al., 2002; Price & Le Masurier, 2007; Smith & Reeves, 2009; Snaith et al., 2015), studies on the impact of immediate X-ray reporting (Brealey & Scuffham, 2005; Hardy et al., 2013; Snaith et al., 2013), and auditing (Jones & Manning, 2008; Stephenson et al., 2012).

The participant sample within this study included reporting radiographers from the UK to assure rigour in design and transparency in results. Sampling and recruitment echoed Milner and Snaith's (2017) approach due to no list of reporting radiographers exists.

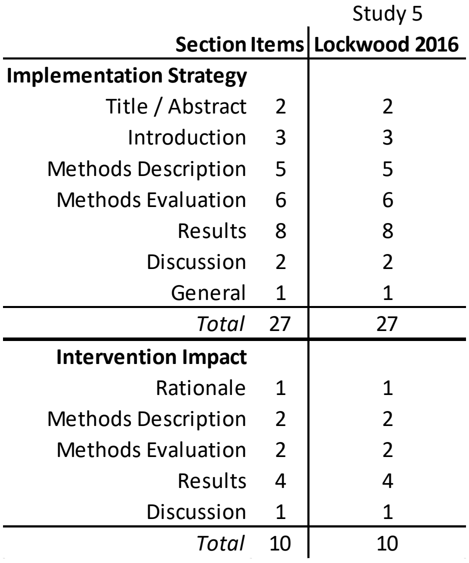
A literature review of professional documents identified occupational standards of core advanced practice role duties that broadly aligned to Manley's (1997) four pillars framework, which were used to set the survey categories (Qualtrics, 2017), focusing on the scope of practice, resources and equipment to perform the role, measures of performance, and Continuing Professional Development (CPD) within the role. A pragmatic approach using a 5-point Likert scale survey was used, with Chi-Square tests for categorical response trends and qualitative free-text responses coded to identify common themes.

The participant sample (n=261) covered X-ray reporting (73%), CT reporting (8%), MRI reporting (5%) and mammography reporting (14%). The outcomes indicated adherence to recommended best practice guidelines in reporting were not consistent within this sample group. The majority of radiographers (74%) had a defined scheme of work and scope of practice. However, it did not necessarily equate to parity of equipment or adequate working environments (48%) that radiologists had access to. The results demonstrated inconsistent quality control activities of auditing and multi-disciplinary team meetings (MDT) attendance, with reduced organisational support for CPD and training opportunities. These issues were important to highlight as potential contributing factors of staff shortages, excessive workloads, inadequate equipment and audit programmes, deficient communication protocols, and lack of discrepancy meetings increase the potential for error (Brady et al., 2012; GIRFT, 2020).

Milner and Snaith (2017) published a similar survey the same year on X-ray reporting radiographers and substantiated similar findings on MDT meetings attendance, audit participation, mentoring, and educational opportunities. Likewise, Henderson et al. (2017) highlighted similar issues of lack of contingency planning for leave, CPD, peer review issues, and lack of standardisation of practice.

In summary, the results of study 5 demonstrated trained CT head reporting radiographer's adherence to scope of practices, team working, MDT attendance and communication with clinicians to evidence level 3, 4, and 5 in Fryback and Thornbury's (1991) framework.

The study was reviewed with the StaRI (2017) checklist (figure 10), assessing the implementation strategy and the impact of the intervention (table 24). The critique appraised the rigour in study design, data collection, analysis and identified no concerns in the study's reporting or methodological standards, as demonstrated by the score of 37/37.



Section	Items	Study 5 Lockwood 2016
Implementation Strategy		
Title / Abstract	2	2
Introduction	3	3
Methods Description	5	5
Methods Evaluation	6	6
Results	8	8
Discussion	2	2
General	1	1
Total	27	27
Intervention Impact		
Rationale	1	1
Methods Description	2	2
Methods Evaluation	2	2
Results	4	4
Discussion	1	1
Total	10	10

Table 24. The StaRI (2017) score of study 5 confirming the study design met implementation science standards.

2.6 Study 6

Lockwood, P. (2020) 'An evaluation of CT head reporting radiographers' scope of practice within the United Kingdom', *Radiography*, 26(2), pp. 102-109.

This cross-sectional survey commenced data collection in 2019. At publication in May 2020, the research evidenced new data on the implementation of trained CT head reporting radiographers in the NHS and the impact of the role within the clinical pathway. It aligned to levels 3, 4 and 5 in Fryback and Thornbury's (1991) efficacy framework for clinical utility (figure 11).

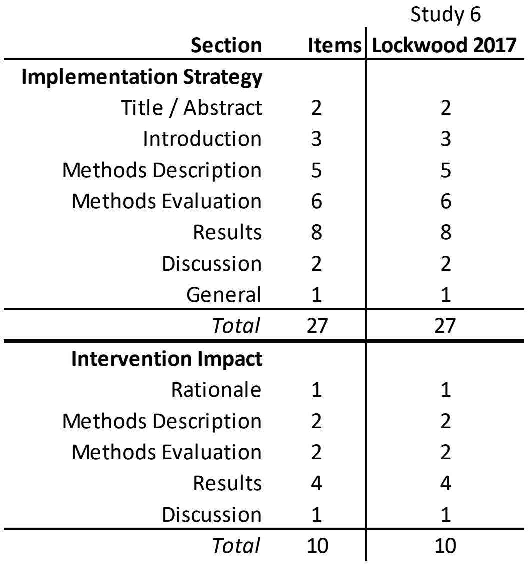
The study recruited *n*=54 CT head reporting radiographers from England, Scotland, and Northern Ireland; no survey returns were received from Welsh healthcare practice. The survey contained a pragmatic method of quantitative (multiple choice and multiple responses) and qualitative (free-text response) questions on key areas from professional guidance (HCPC, 2013; SCoR, 2013; RCR, 2018b; CT Head SIG, 2012) addressing themes on the scope of practice, referrals, and ongoing competence.

The responses on scope of practice provided data on patient referral criteria and patients' demographics, showing radiographers scope of practice was not limited by a narrow patient pathway and included all hospital referral routes. The data evidenced onward referral for additional medical imaging when required, attesting actionable reports that communicated referral to recommended specialist medical and surgical teams for specific treatment, management, and pharmaceutical drug therapies. Fryback and Thornbury (1991) define levels 3, 4 and 5 as aiding downstream management decisions to initiate treatment (e.g. thrombolysis medication), modify it, stop, or withhold treatment (end of life care). As attested to in the participant responses linking 'diagnostic accuracy' to 'clinical utility' in defined target conditions (Bossuyt et al., 2012) of stroke, cancer and trauma examples, resulting in outcome changes (level 5) of Fryback and Thornbury (1991).

The corroboration of both qualification and years of clinical reporting experience increased the participants' testimonial validity. The data confirmed that the sample group aligned their clinical practice to national guidance compared to the variance identified in study 5. Working to strictly defined protocols and scope of practices reduces the legal basis for negligence in medical practice (Brady et al., 2012). Studies 1- 4 established error rates that were less than published radiologist discrepancy rates of 13% (Briggs et al., 2008), radiographer error would need to exceed this acceptable norm (Bolam test) for it to be considered a legal negligence judgement (Diamond, 2002; Alderson & Hogg, 2003; Brady et al., 2012).

In summary, study 6 was critical to building upon the findings of study 5 and demonstrated the impact of the role upon the patient pathway to benefit clinical decision making on treatment and management to improve patient outcomes to evidence Fryback and Thornbury (1991) levels 3, 4, and 5 (figure 11).

The study was evaluated against the StaRI (2017) framework checklist, assessing the implementation and the impact of the intervention (table 25). The critique appraised the study design, data collection, analysis, and reporting of the study, resulting in a score of 37/37.



Section	Items	Study 6 Lockwood 2017
Implementation Strategy		
Title / Abstract	2	2
Introduction	3	3
Methods Description	5	5
Methods Evaluation	6	6
Results	8	8
Discussion	2	2
General	1	1
Total	27	27
Intervention Impact		
Rationale	1	1
Methods Description	2	2
Methods Evaluation	2	2
Results	4	4
Discussion	1	1
Total	10	10

Table 25. The StaRI (2017) score of study 6 confirming the study design met implementation science standards.

2.7 Study 7

Lockwood, P. (2016) 'An economic evaluation of introducing a skills mix approach to CT head reporting in clinical practice', *Radiography*, 22(2), pp. 124-130.

This study was the first and only economic evaluation study to explore the trained radiographer CT head reporting role aligned to level 6 of the Fryback and Thornbury (1991) efficacy framework (figure 11).

The study applied an audit-based sample of patients attending CT head examinations at an NHS hospital over 12 months. The study modelled the costs of a single trained CT head radiographer reporting role against a radiologist comparator using decision tree modelling, discount rates, estimation of resources, costs, and parameters characterising uncertainty and heterogeneity due to incremental variations between the two roles. Applying NHS Monitor (2013) and NICE (2014b) national tariff costings allowed the calculation of potential annual cost savings from implementing the trained CT head reporting radiographer in an NHS district general hospital setting. Justifying the study to base costings on full-time reporting roles was rationalised in the 'comparison of costs per intervention' section of study 7. Taking the pragmatic stance that in 'real world' scenarios, radiologists do not report all day every day and have additional duties (Programmed Activities (PAs) for the administration of paperwork, teaching, study, (RCR, 2012d) and other clinical roles but acknowledge these are often at an equivalent level of skills to their reporting. For the radiographer role to allow direct 'comparison of costs per intervention', this was also calculated on full-time reporting. Although it is accepted in 'real world' clinical departments, there may not be sufficient patient caseloads at individual hospital departments to allocate a full days' worth of reporting sessions. Radiographers may be required to do non-reporting clinical duties, as evidenced in study 5 findings of regional variations of implementation of the role.

Considering the implications of non-reporting time to these different professions may mean an overpayment during non-reporting duties which may affect the unit of analysis costing per different profession. But the stance in the study to calculate full time reporting costings aligned to professional bodies policy of the role by the RCR (2012d) and the SCoR (2013). The SCoR (2013, section 6.4) policy uses CT head reporting as an example, stating radiographers demonstrating a scope of practice supported by their training and postgraduate qualification in reporting should be renumerated at the equivalent Agenda of Change pay spine banding (7 or 8), the policy does not advocate fractionation of pay spines to daily clinical roles (i.e. lower banding payment when not reporting).

Translation of the research into implementation evidence for the utility of radiographer reporting cost-effectiveness based on a full-time role is strengthened by workforce development opportunities of hub and spoke models of reporting through regional imaging network hubs that share reporting across regions and community screening hubs (NHS, 2020b) that would provide a reporting caseload to fulfil a full-time role.

Ethical approval constraints restricted access to reviewing patient records for outcome treatment and management decisions post-CT report, which meant calculating incremental cost-effectiveness ratio (ICER) and quality-adjusted life-year (QALY) analysis was not possible. Previous studies by Tilford et al. (2007); Melzer (2012); Bossuyt et al. (2012); and Grieve et al. (2016) found calculating ICERs and QALYs complex in this scenario. Assessing the ICER and QALYs gained by who reports the image (reporting radiographer vs radiologist) would need to factor condition-specific analysis (TBI, stroke, cancer, dementia, etc.), severity scoring of each condition, pre-existing medical conditions, variations to treatment (neurosurgical intervention vs medical observation) to estimate life expectancies, of which there is too much inherent variability to sufficiently be conclusive.

In summary, the findings demonstrated that within an NHS hospital setting, utilising trained radiographers to report CT head examinations is cost-efficient and applies cost savings (up to £328,865) compared to consultant radiologist service delivery. The cost-benefit to the healthcare service of trained radiographer reporting in terms of service (efficacy from studies 1 – 4, clinical utility from studies 5 - 6), potential to increase reporting capacity, decrease reporting TATs delays, and improve time-critical neurological outcomes (validity), providing evidence to achieve level 6 'societal efficacy' of the Fryback and Thornbury (1991) framework.

The study was scrutinised against the CHEERS (2013) framework (figure 10) criteria on the objectives, settings, comparators, time horizon, decision tree modelling, discount rates, and measure of estimating resources and costs (table 26). A total score of 27/27 reflected the study reported all the data comprehensively.

		Study 7
Section	**Items**	**Lockwood 2016**
Title / Abstract	2	2
Introduction	1	1
Methods	16	16
Results	5	5
Discussion	1	1
Other	2	2
Total	27	27

Table 26. The CHEERS (2013) checklist score of study 7 of model-based health economic evaluations study design.

2.8 Meta-analysis of studies 1 - 4

Studies 1 – 4 provide homogeneous study methods and populations which were sufficiently comparable (table 27). The meta-analysis used Meta-DiSc v1.4 (Zamora, 2006) software to calculate an overall pooled sensitivity of 89% and pooled specificity of 95% (figures 12 – 13), which demonstrates a higher level of ability and performance than the published literature review in 1.10.4. The heterogeneity inconsistency (I^2) determined heterogeneity was present in the sensitivity result; thus, it was further investigated with a ROC curve summary estimate (figure 14).

The radiographer's AUC was 0.98 (SE 0.0), higher than the previously published literature (figure 9). Korevaar et al. (2019) advise that for studies to be used as evidence, the outcomes would need to be at a minimum equivalent to the existing reference standard (radiologists) confirmed by study 2 radiologist AUC 0.93 - 95 (literature review), and study 4 radiologists AUC of 0.83 - 94 (SE 0.01 - 0.03).

Study, Year	**Study Type**	**Radiographer sample size**	**CT Cases total**	**Patient age range**	**Results**				
					Sens	**Spec**	**Acc**	**Agree**	**AUC**
Study 1 : Lockwood, Piper, Pittock, 2015	Reporting	*n* =24	*n* =600	Adult	99.4%	95.9%		90.6%	
Study 2 : Lockwood 2017	Reporting	*n* =6	*n* =144	Adult	97.5%	93.6%	95.0%		0.98
Study 3 : Lockwood 2017	Reporting	*n* =6	*n* =3,008	Mixed	86.9%	94.0%	90.7%		
Study 4 : Lockwood and Piper, 2015	Reporting	*n=6*	*n* =240	Mixed	88.7%	95.6%		92.2%	0.97

Table 27. Statistical outcome measures of studies 1 – 4.

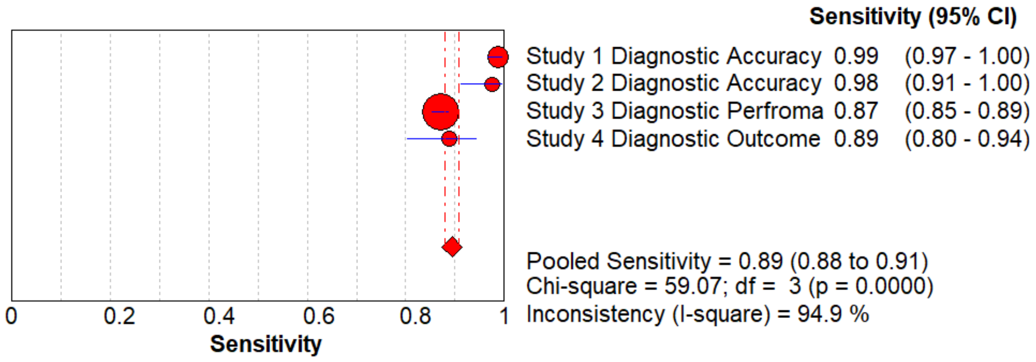


Figure 12. Studies 1- 4 forest plots of high sensitivity (efficacy) for radiographer's reporting CT head scans.

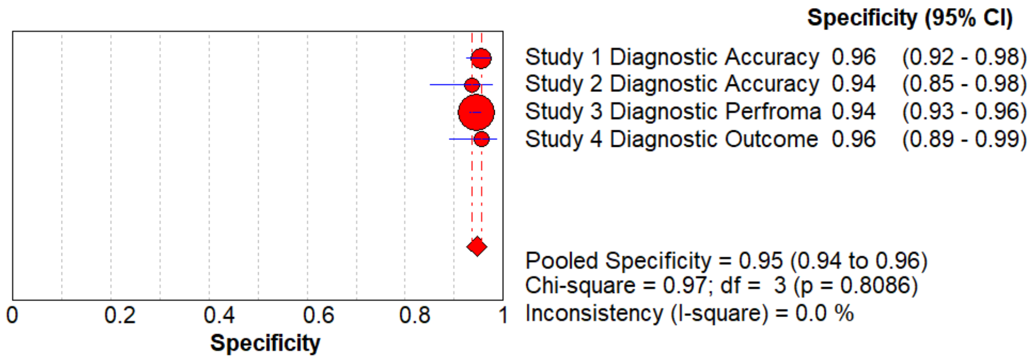
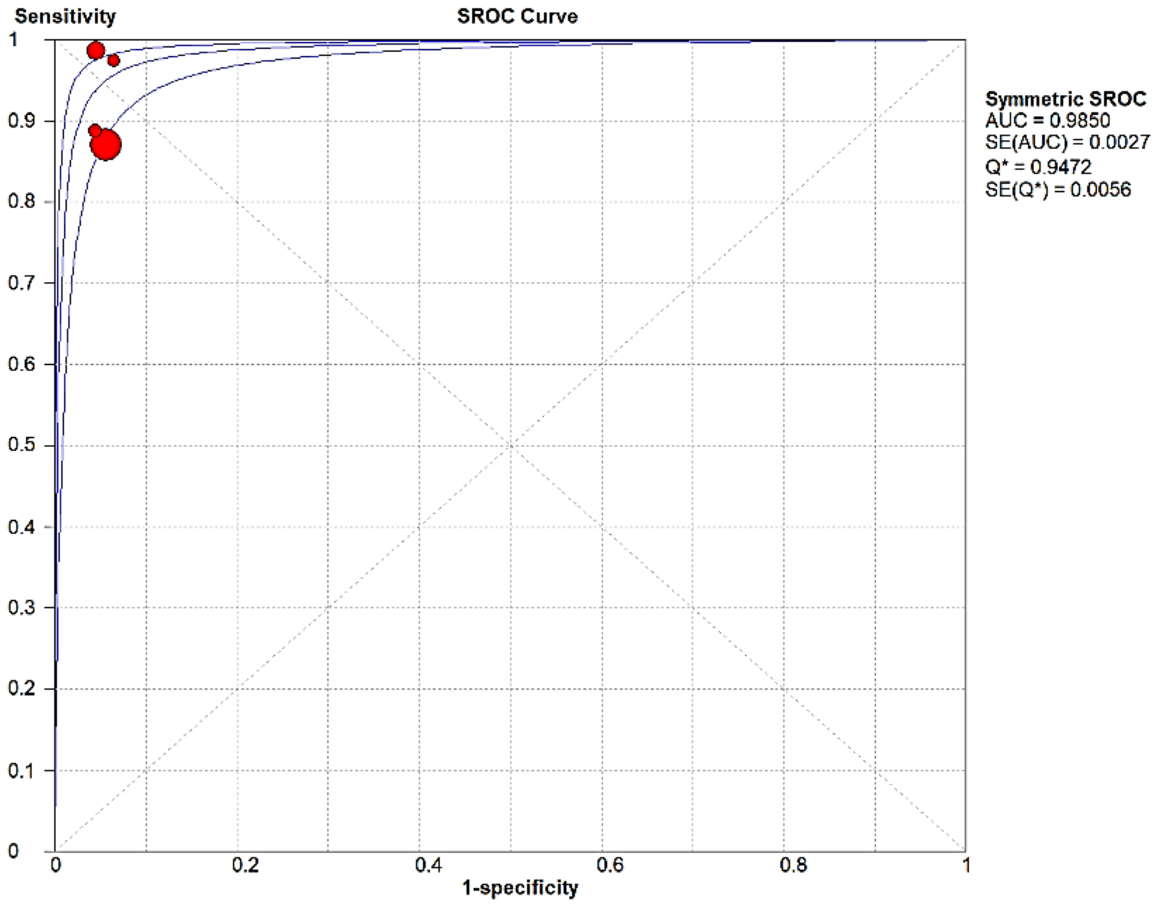


Figure 13. Studies 1- 4 forest plots of high specificity (efficacy) for radiographer's reporting CT head scans.



Figures 14. Studies 1 - 4 summary ROC Curve indicating 0.98 AUC for the radiographer's diagnostic accuracy in CT head reporting.

2.9 Conclusion

The research (studies 1 – 4) demonstrated consistently high levels of reporting efficacy (table 27; figure 14) equivalent to consultant radiologist clinical practice. To err is human (Kohn et al., 1999) and the reporting radiographer discordant discrepancy rates (false positives / false negative errors) did not exceed the acceptable norm (Bolam test) of consultant radiologist rates for clinically important levels of error.

Fifteen years ago, concerns about radiographers (X-ray) reports were that they were only descriptive (Donovan & Manning, 2006) and thus alleged to be of limited use to support clinical decisions and management for patients. Emerging from the critical review of the submitted studies on clinical utility and validity (5, 6) it is clear evidence that trained radiographer reports communicate actionable advice on a range of downstream clinical judgements, such as medical options (pharmaceutical therapy) and surgical referral to specialist neurosurgical centres (studies 5 - 6). The cost-effectiveness and cost-benefit analysis (study 7) using decision tree modelling (Thornbury, 1994; Plevritis, 2005; Geist, 2017) and deductive reasoning summarised a cumulative advantage incentive of cost savings (up to £328,865 per annum per radiographer) of implementing CT head reporting radiographers within the NHS.

Limitations to the clinical utility outcomes (acknowledged in 2.7) were the ethical constraints to calculate ICERs and QALYS in study 7. Future observational studies may be possible with NHS ethical approval on specific pathways such as stroke, TBI or subarachnoid haemorrhage (NICE, 2017; 2018b; 2019b) to track patient records post report to see if the MDT follows the radiographers report recommendations of surgical (NICE, 2017; 2018b) or therapeutic (NICE, 2019b) management as recommended by the Healthcare Safety Investigations Branch (HSIB, 2018) guidance for clinicians to act on all radiology reports. Nevertheless, assessing patient outcomes correlated to the CT imaging report is multifactorial. It requires consideration of both patient decisions, which Bossuyt et al. (2012) describe as 'personal utility' and often termed 'social utility' (Brealey et al., 2005b) in conjunction with physician judgements of 'thinking efficacy' (Plevritis, 2005; Sistrom, 2009). The imaging report is but one test combined with medical histories, blood chemistry results, physical examinations, pre-existing conditions, and patient choice/consent, which impact patient outcomes (Mabotuwana et al., 2018; Galinato et al., 2019).

Section 3

3.0 Contribution of the research to the development of new knowledge

The impact of dissemination of the research (studies 1 - 7) can be measured by its citations (69 times; appendix 4), of which 49 are in national and international peer-review journals. The research has been described as making a significant contribution to the efficacy, clinical utility and validity of the advanced practice role of trained radiographer reporting (Woznitza & Keane, 2015; Nightingale & McNulty, 2016; Hardy et al., 2016; Thom, 2018; Culpan et al., 2019) helping to justify continued training programmes for radiographers reporting CT head scans, and support service improvement to manage demand effectively.

The efficacy outcomes in Study 1 were presented at the inaugural international radiographer advanced practice conference 'Leading the Way in Radiography Practice' (2016) held at Sheffield Hallam University, to a global audience from America, Australia, Canada, and New Zealand. Study 1 was also presented at the 2014 UK Radiological Congress (UKRC), and studies 2, 3, 4, 7 at the 2017 UKRC, with study 7 winning the 2017 Runner Up Best Scientific Research Poster.

Nightingale and McNulty (2016) emphasise that successful delivery of radiology services relies upon a skills mix approach and cite studies 1 and 7 as a proposed solution and evidence to '*champion*' an effective change at local and national levels. Nightingale and McNulty (2016, p.232) stated that these are "*tangible benefits that will improve report turnaround times with no adverse effects in terms of patient safety and outcomes*" reiterating the found efficacy, clinical utility and validity of the research aims.

Hardy et al. (2016) cited study 7 within their systematic review into how trained reporting radiographers' advanced practice improves patients' outcomes and health service quality. Hardy et al. (2016) scored study 7 as the second-highest study in their literature review, citing the value of the output and its direct relevance for clinical practice.

A further contribution of the research to new knowledge has been cited by Thom (2018) in the systematic review of advance practice radiographer reporting benefits to the NHS. Thom (2018) directly cited study 7 as a cost-effective approach where patients benefit from the quality of their examination result, the report's high efficacy, and the increase in report TATs. With additional benefits of radiographer job satisfaction and reduced reporting backlogs.

The most extensive systematic literature review to date on reporting radiographers by Culpan et al. (2019) cited the contribution of studies 1, 2, 5 and 7 to support the Health Education England (HEE) Cancer Workforce Plan (2017) in expanding the reporting service provision within the UK, and the NHS Benchmarking (2017) endorsement of radiographer reporting as a national approach to the continuous growth in demand for clinical imaging. Culpan et al. (2019) cited studies 1 and 2 to demonstrate training standards and high levels of efficacy in reporting, study 5 as evidence of scope of practice and interprofessional team working within the patient pathway, and study 7 for cost savings. Endorsing the clinical utility and validity that CT head reporting radiographers working within interprofessional clinical teams improve patient pathways and outcomes. Culpan et al. (2019) advised that failure in future investment in radiographer reporting initiatives to increase reporting capacity will jeopardise the Independent Cancer Taskforce's recommendations (2015).

3.1 Implications for future research, policy, and practice

Di Michele et al. (2020, p.27) advises that the benefits of "*translating knowledge into evidence-based practice in diagnostic radiography are wide reaching with positive implications for our patients, the profession and wider community*". Noted with the validity of implementing CT head reporting to reduce reporting TAT delays (Woznitza, 2014), the value of the scope of practice to benefit the healthcare service provision of diagnosis in trauma, health screening, treatment and management follow up (studies 5, 6) and the cost to society and the NHS (study 7). Closing the gap between the evidence and clinical practice by key stakeholders should be the goal to improving healthcare service (Grol & Grimshaw, 2003; Graham et al., 2006; Grimshaw et al., 2012), but Di Michele et al. (2020, p.30) acknowledges there is no '*one size fits all*' model or framework to translate knowledge into healthcare practice, and a '*cultural shift*' is needed (Thaler & Sunstein, 2009) which the CQC (2018) and GIRFT (2020) reports are attempting for reporting radiographers.

Additionally, there may be future global opportunities for knowledge translation in implementing trained radiographer reporting in countries with similar drivers around an increasingly unstable equilibrium of patient demand and reporting workforce supply. Already Australia (Smith & Baird, 2007), Canada (Talla et al., 2019), Denmark and Sweden (Andersson et al., 2016), Ghana (Wuni et al., 2020), Mexico (Torres-Mejia et al., 2015) and South Africa (du Plessis & Pitcher, 2015) have made tentative steps in radiographer reporting trials to gauge stakeholder acceptance.

3.2 Conclusion

This body of work contributes novel and original findings that trained radiographers report CT head scans to a high efficacy level equivalent to consultant radiologists (studies 1 – 4). Radiographers communicate actionable reports to multidisciplinary teams to impact clinical decisions on treatment and management (studies 5 - 6), evidencing beneficial clinical utility. Radiographers' scope of reporting practice included all referral criteria of trauma, health screening, disease diagnosis, staging, and monitoring treatment, and all patient populations (studies 5 – 6) in a cost-effective and cost-benefit contribution to society and the healthcare service (study 7), attesting to the validity of the role.

The literature review in section 1 on published studies identified an unanticipated finding related to the need for robustness in methodological standards and data analysis to generate translational evidence that was addressed in the research studies within section 2 of this thesis. Through triangulation of the mixed method research approaches of studies 1 - 7, the 'knowledge gap' on efficacy, utility, validity and the economic impact of radiographers reporting CT head scans within section 2 was addressed.

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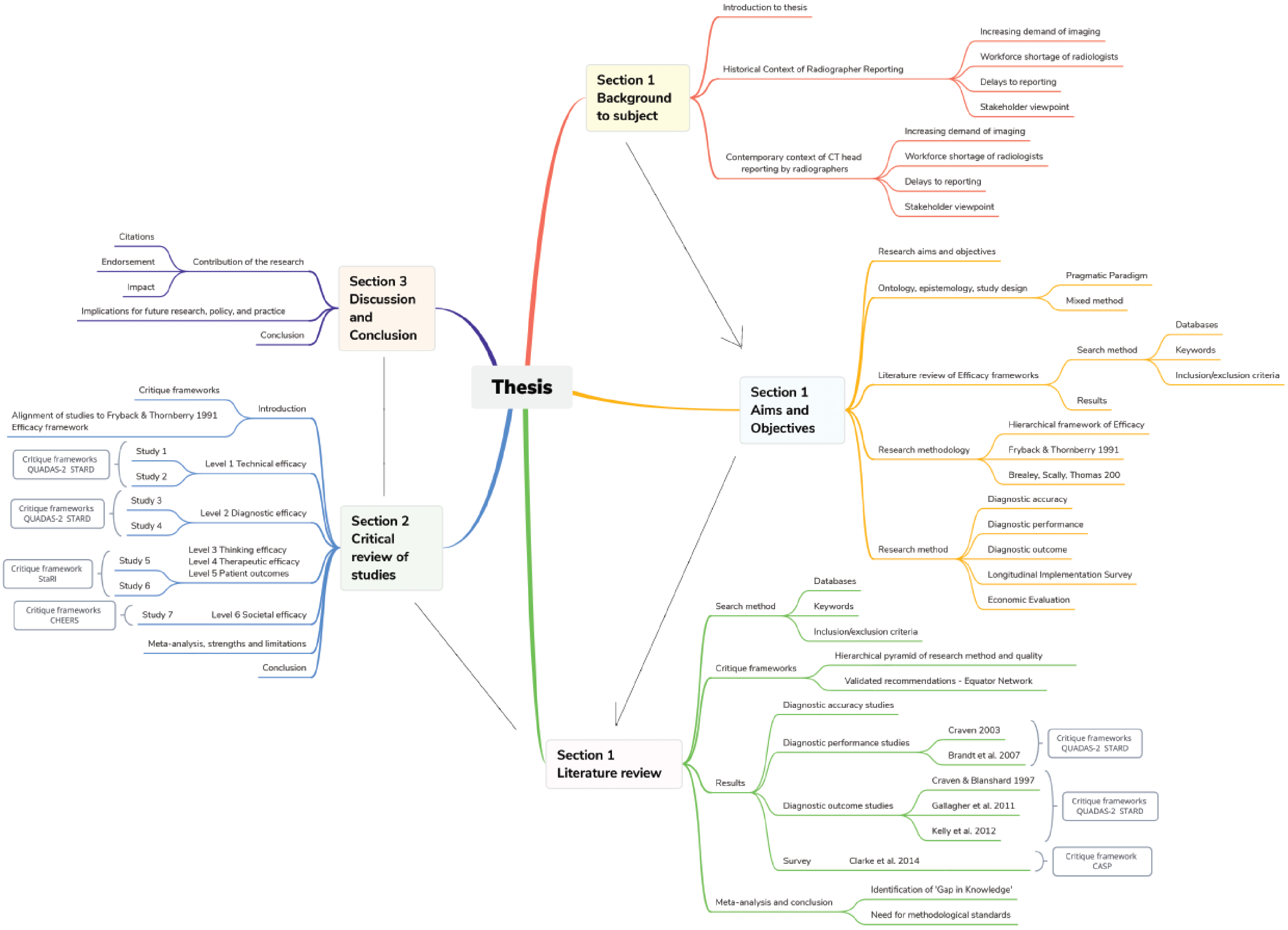
Appendix 1. Concept Map of thesis.



Appendix 2. Substantial Author Contributions for studies 1 - 7

The contribution of all those eligible for co-authorship has been recognised by Paul Lockwood in all the studies included in this PhD by Publication thesis.

- No eligible author has been denied authorship of the opportunity to contribute
- No ineligible author has been included on any publication
- Where appropriate, acknowledgements have been made to participants who do not satisfy enough criteria to be considered a co-author
- Overall contributions to each published article with individual declarations for each study are detailed in Table 1.

The intellectual ownership and type and percentage contribution of all co-authors for each study (1-7) included in this PhD thesis are summarised as:

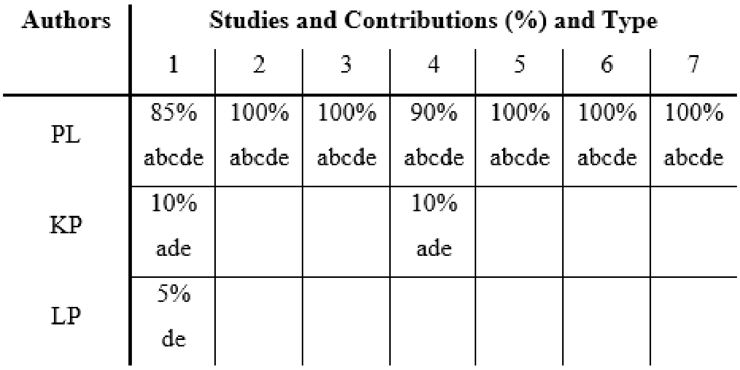
a) Concept and Design

b) Data Collection

c) Data Analysis

d) Drafting and Revision

e) Final Approval



Authors	**Studies and Contributions (%) and Type**						
	1	2	3	4	5	6	7
PL	85% abcde	100% abcde	100% abcde	90% abcde	100% abcde	100% abcde	100% abcde
KP	10% ade			10% ade			
LP	5% de						

This has been based on a subset of categories for authorship as recommended by the International Committee of Medical Journal Editors (International Committee of Medical Journal Editors, n.d.). However, contributors were not denied the opportunity to become authors if they did not fulfil each of the criteria. All co-authors listed had the opportunity to review the final submission.

I hereby declare that the above statements have been satisfied. I sign to acknowledge the contribution of all authors in accordance with the Canterbury Christ Church University regulations.

Signed:

Paul Lockwood (**PL**)
Lead PhD Researcher

Dr Keith Piper (**KP**)
Co-author

Lisa Pittock (**LP**)
Co-author

Appendix 3. Ethical approval confirmation for studies 1-7.

*It is noted that some final published study titles may differ from the wording of the original research ethics application project title, this is due to Journal peer reviewer comments requesting changes pre-publication.

Study 1

Ethics application: 14/NHP/Lockwood

Published paper: Lockwood, P., Piper, K., Pittock, L. (2015) ‘CT head reporting by radiographers: Results of an accredited postgraduate programme’, *Radiography*, 21(3), pp. e85 - e89.

Study 2

Ethics application: 16/H&W/CL141

Published paper: Lockwood, P. (2017) ‘CT sinus and facial bones reporting by radiographers: findings of an accredited postgraduate programme’, *Dentomaxillofacial Radiology*, 46(5), p 20160440, pp 1 - 11.

Study 3

Ethics application: 16/H&W/CL143

Published paper: Lockwood, P. (2017) ‘Observer performance in Computed Tomography head reporting’, *Journal of Medical Imaging and Radiation Sciences*, 48(1), pp 22 - 29.

Study 4

Ethics application: 13/H&SC/CL66

Published paper: Lockwood, P., Piper, K. (2015) ‘AFROC analysis of reporting radiographer's performance in CT head interpretation’, *Radiography*, 21(3), pp e90 - e95.

Study 5

Ethics application: 15/H&W/CL115

Published paper: Lockwood, P. (2017) ‘Exploring variation and trends in adherence to national occupational standards for reporting radiographers’, *Journal of Social Science and Allied Health Professions*, 1(1), pp 20 - 27.

Study 6

Ethics application: 15/H&W/CL115

Published paper: Lockwood, P. (2020) ‘An evaluation of CT head reporting radiographers' scope of practice within the United Kingdom’, *Radiography*, 26(2), pp 102 - 109.

Study 7

Ethics application: 15/H&W/CL116

Published paper: Lockwood, P. (2016) ‘An economic evaluation of introducing a skills mix approach to CT head reporting in clinical practice’, *Radiography*, 22(2), pp 124 - 130.

Appendix 4. Citations of studies 1 - 7.

The influence and impact of the individual published papers based on the research studies submitted are displayed in tables providing a breakdown of citations (including self-citations by co-authors). Some studies have only recently been published and may not have had time to circulate within the sector enough to be cited as yet.

Citations are either peer review journal article or other citation coded as:

A - Academic thesis

C - Conference document

U – Unrefereed article

B - Book

Study 1

Lockwood, P., Piper, K., Pittock, L. (2015) 'CT head reporting by radiographers: Results of an accredited postgraduate programme', *Radiography*, 21(3), pp e85-e89.

Article Citations

1. Lockwood, P., Piper, K. and Pittock, L. (2016) 'CT head reporting by radiographers: Results of an accredited postgraduate programme', *Radiography: Advanced Practice Virtual Issue Leading the Way Radiography Advanced Practice Conference*, September 2016.
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Study 2

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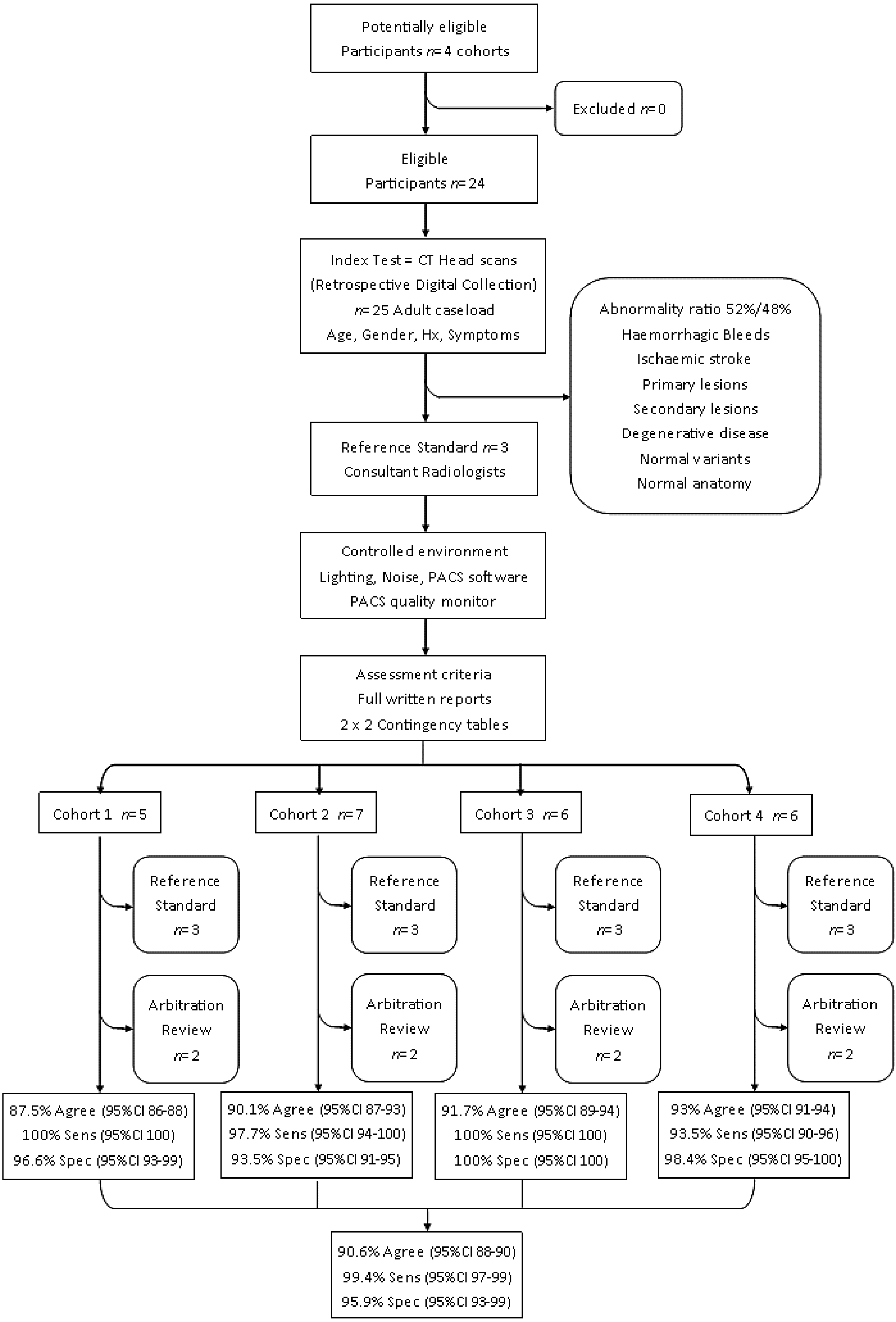
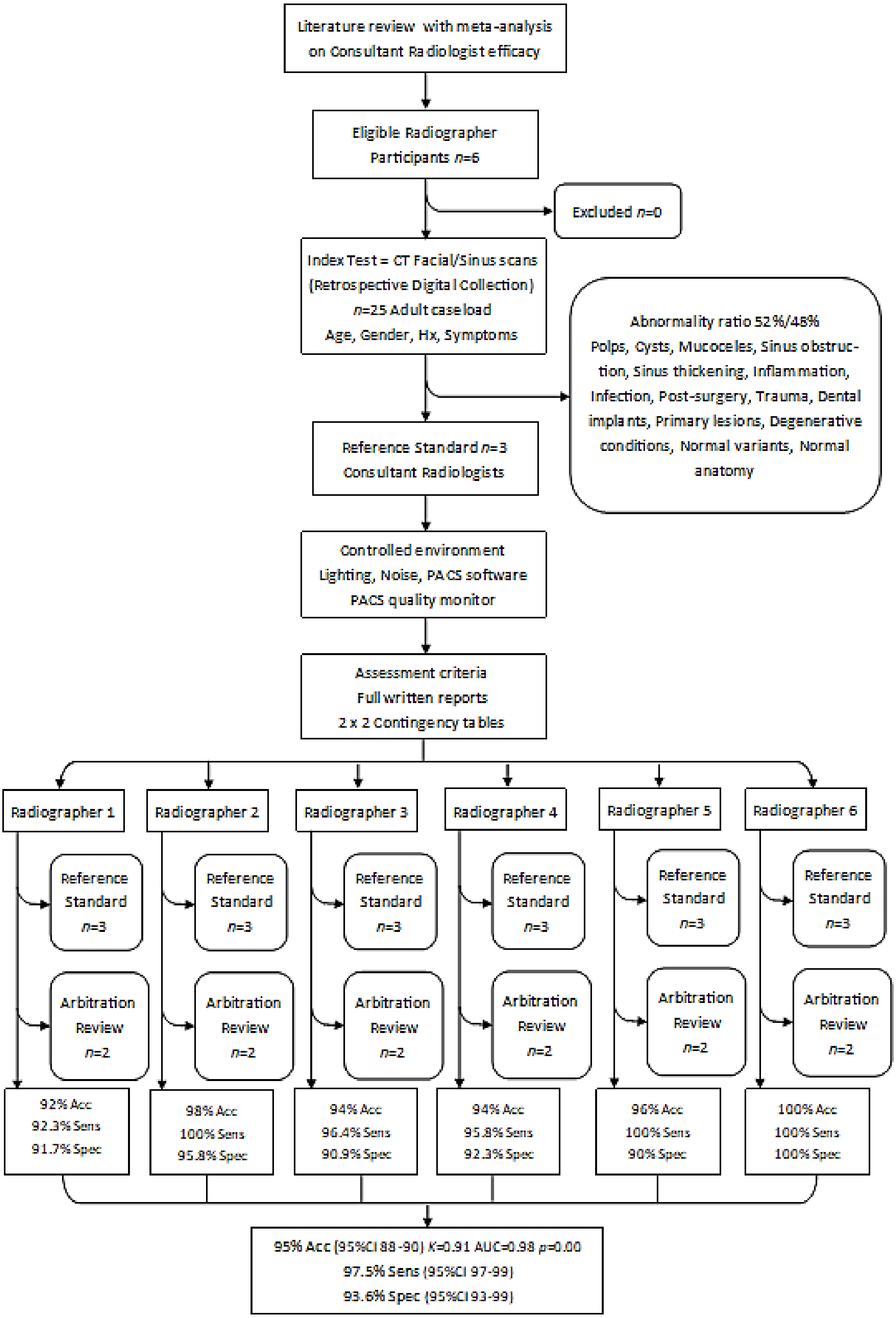
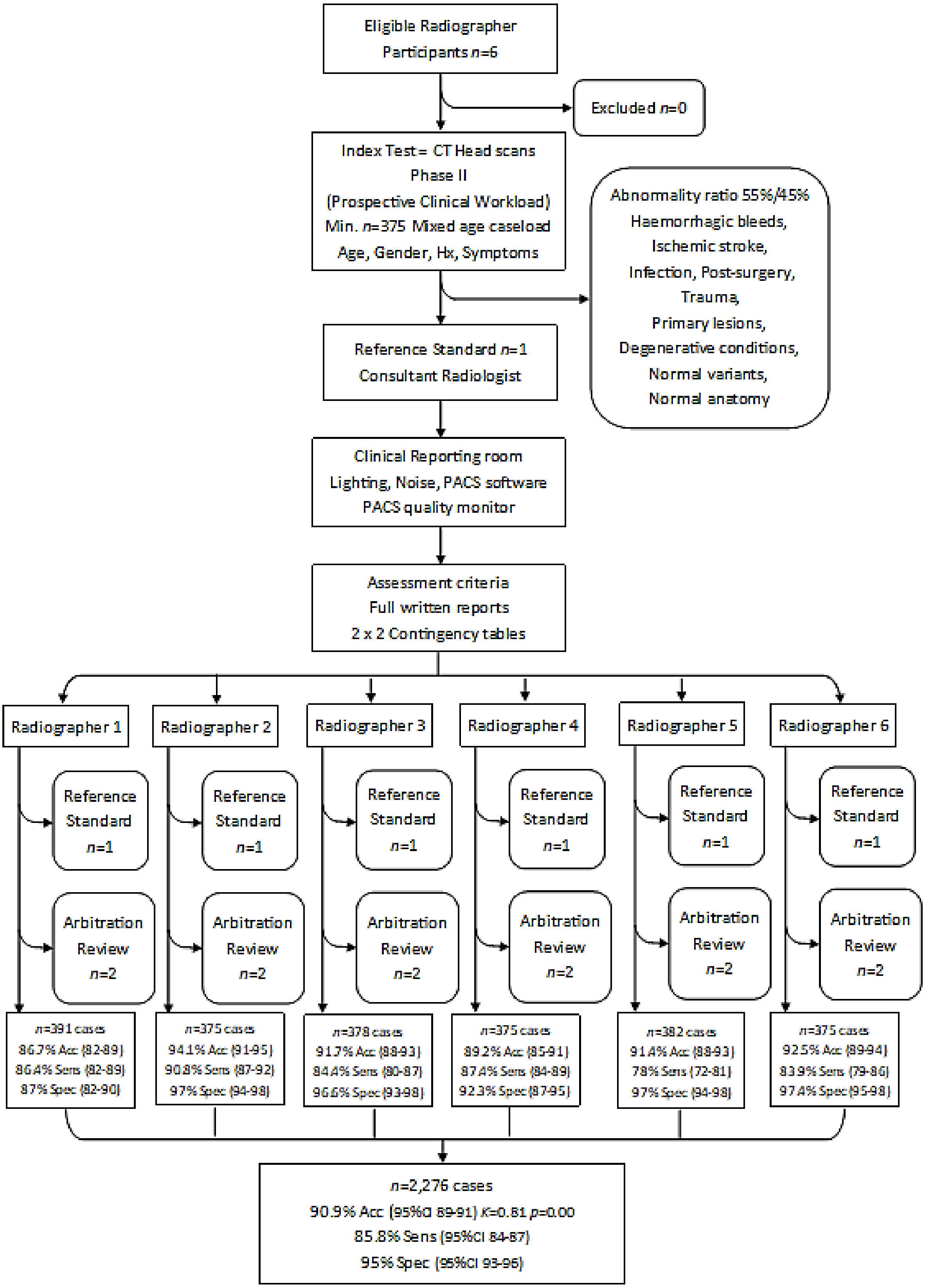
Appendix 5. Study 1 flow chart.



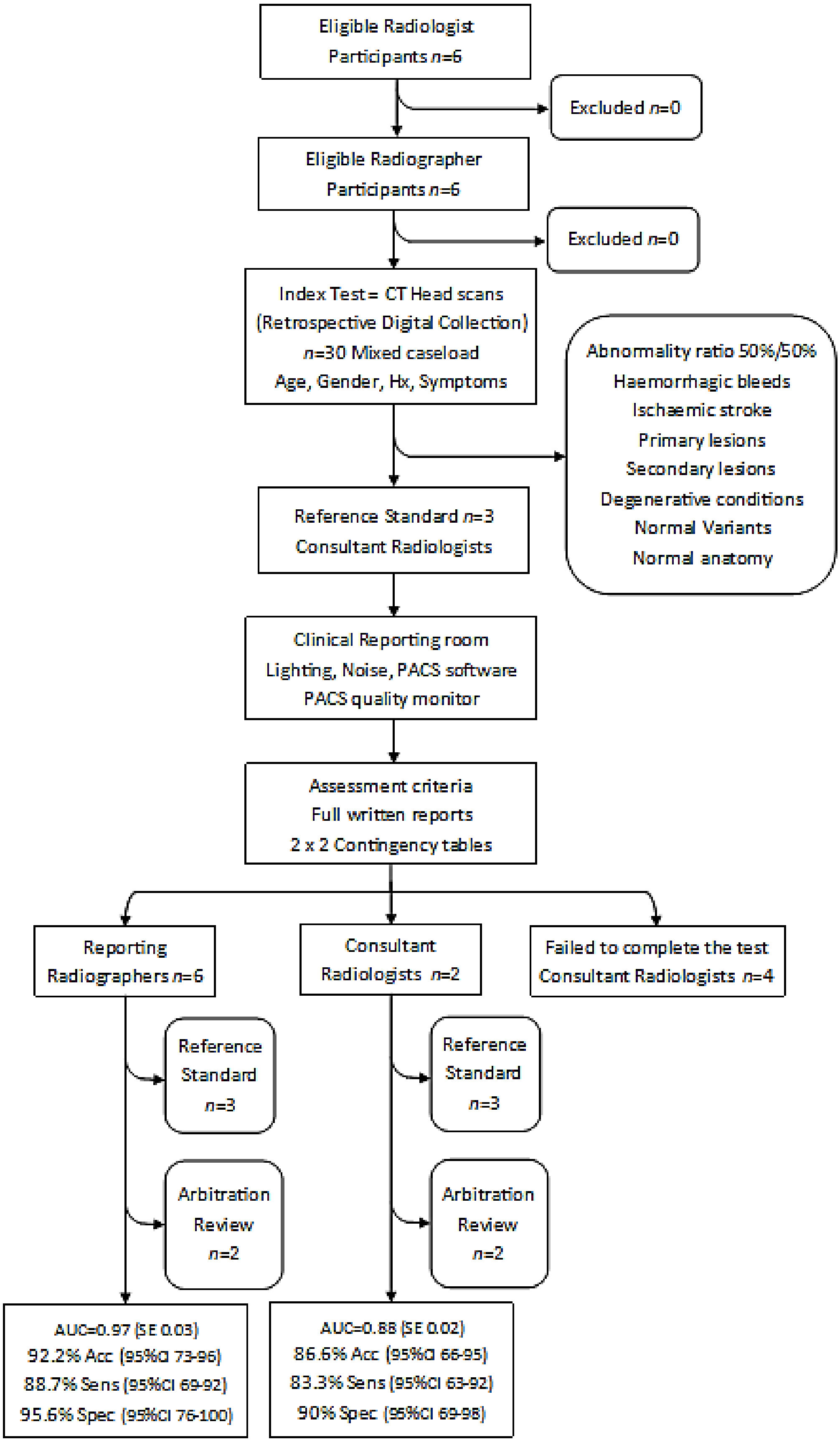
Appendix 6. Study 2 flow chart.



Appendix 7. Study 3 flow chart.



Appendix 8. Study 4 flow chart.



Annexe of submitted studies

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CT head reporting by radiographers: Results of an accredited postgraduate programme

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A B S T R A C T

Aim: To evaluate the results of the summative objective structured examination (OSE) for the first four cohorts of radiographers ($n = 24$) undertaking an accredited postgraduate course in reporting computer tomography (CT) head examinations.

Method: The construction of a summative OSE contained twenty five CT head examinations that incorporated 1:1 normal to abnormal pathological examples. All cases were blind reported by three consultant radiologists to produce a valid reference standard report for comparison with the radiographer's interpretation. The radiographers ($n = 24$) final reports ($n = 600$) were analysed to determine the sensitivity, specificity and agreement values and concordance for the four cohorts.

Results: The four cohorts (2007–2013) of postgraduate radiography students' collective OSE results established a mean sensitivity rate of 99%, specificity 95% and agreement concordance rates of 90%. The final grades indicate that within an academic environment, trained radiographers possess high levels of diagnostic performance accuracy in the interpretation of CT head examinations.

Introduction

The role and scope of radiographer reporting of computer tomography (CT) examinations is still an evolving practice in the United Kingdom (UK). A recent survey by the Society and College of Radiographers (SCoR)[1] established at least 17 sites in the UK are now supporting this role extension and to assist service provision. Support to develop radiographers' roles into this area of practice has been promoted by Royal College of Radiologists (RCR) and the SCoR team working guidance.[2] Evidence to develop reporting radiographers in practice has been illustrated through the RCR Clinical Radiology Workforce report[3] which established the current working population of radiologists within the UK and suggested the considerable challenges posed by the shortage of radiologists, and the increasing amount of unreported imaging. This has led some clinical radiology departments to introduce an effective skills mix of radiologists and radiographers reporting to cope with the current demand in imaging services and report turnaround times.[4]

Important drivers that have encouraged this role extension include the impact of dedicated guidance to recommend timescales for reporting. The National Diagnostics Imaging Board (NDIB)[5] issued guidance advocating that reporting turnaround times for urgent imaging examinations to be within 30 minutes, inpatients and accident and emergency patients within the same working day, and ideally all other cases by next working day. Specifically the National Institute for Health and Care Excellence (NICE) Head Injury guidelines (CG176)[6] key priorities and recommendations include CT scanning patients with suspected head injuries within 1 hour of admission with a written provisional CT report within 1 hour of scanning. The NICE Stroke guidance (CG68[7] and QS2[8]) recommends immediate CT scanning and recognises the importance of urgent CT reporting on the therapy management and treatment of the acute patient.

A study by Clarke et al.[9] which included 23 service managers and 48 CT head reporting radiographers attempted to identify key barriers to the development and implementation of CT head reporting by radiographers. Factors included a lack or reluctance of radiologists to participate as mentors in training and teaching, and staff shortages reducing the possibility of radiographers being released to study. Both of which have impacted upon the number of candidates applying for places on postgraduate programmes over recent years, this has led to a decrease in the availability of post graduate courses provided by higher education institutes in the UK.[9] Several National Health Service (NHS) Trust Imaging

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departments[1] have taken action in response to these policies[2,4–8] and guides[10] and commenced role extension initiatives supported by the SCoR[11] to instigate CT head reporting by radiographers who have attained a recognised qualification in CT head reporting.

Radiographers undertaking an approved course of training have the potential to improve service delivery and provide an innovative approach to reporting demands and capacity.[3,4,6–8] The 12 month postgraduate programme in clinical reporting of CT head examinations at Canterbury Christ Church University (CCCU) consists of clinical department tutorials and clinical experience in reporting, supported by a series of briefing blocks conducted at the university campus every three months throughout the programme.[12] Consultant radiologists with extensive CT experience and proficient CT head reporting radiographers participate in the construction, organisation, lecturing and assessment components of the curriculum. The assessment strategy includes a written clinical case study, a reflective audit of the student's developing competence in CT head reporting and 375 written reports, 250 reviewed and evaluated by the students allocated workplace consultant radiologist mentor. The final assessment of the student's ability to report CT head examinations concludes with the interpretation of an objective structured examination (OSE) image bank of 25 CT head examinations.

Objectives

1. To analyse and establish the diagnostic performance accuracy of the first four cohorts of radiography students who finished the postgraduate programme in CT head reporting.
2. To evaluate the concordance ratio for a small representative cohort of radiographers against the reference standard of a small designated sample of radiologists.

Method

An element of the candidate's proficiency of the training involved the students reporting a bank of 25 CT head investigations in the format of a written OSE under controlled examination conditions using low level lighting and high definition reporting monitors[13] that meet the 2012 RCR reporting specification standards[14] (42 cm, 1280 × 1084 screen resolution, >170 cd/m^2 luminance, $\geq 250{:}1$ luminance contrast ratio). The case studies were displayed in Digital Imaging and Communications in Medicine (DICOM) format using KPACS software[15] to enable manipulation.[14]

During the construction of the OSE, a large bank of CT investigations were reported independently by three experienced consultant radiologists who routinely report CT head examinations as part of their clinical role. Twenty five cases of CT head investigations of 1:1 normal to abnormal examples were agreed upon. Expected responses (compiled from the reports of three consultant radiologists) for each of the 25 examinations submitted for each OSE, were then agreed and approved by the programme panel and external examiner (independent consultant radiologist), who verified that a suitable range of subtle discriminatory examples were incorporated. A variety of investigations were featured to sufficiently assess the students' knowledge and skills whilst demonstrating competence and proficiency to a high degree. Characteristic abnormal pathological examples included a range of: acute and chronic subdural and extradural hematomas, subarachnoid haemorrhages, intracranial and intraventricular haemorrhages (including traumatic multi-site haemorrhages with cranial fractures). Ischaemic and haemorrhagic infarctions, primary and secondary malignant and benign cerebral tumours. With additional incidental findings, particularly in the cerebral hemisphere category, including ischaemic small vessel disease, physiological involution, benign calcification, and previous surgical intervention.

Candidates were provided with demographic details which included each individual case's patient details including gender, age, referral source (accident and emergency, in-patient, out-patient or general practitioner) and clinical history provided at the original CT investigation. The candidates were required to state if the examination was normal or abnormal, detailing their evaluation on a pre-provided answer booklet by ticking a formatted checkbox. The radiographers were further instructed to categorise normal variant anomalies as normal. If the investigation was deemed abnormal the candidates were then required to write a detailed report outlining the key abnormal findings and suggested pathology(ies), and where necessary supporting differential diagnosis, in the form of a free text response answer. During the course of the programme candidates were taught to provide logically organised responses to identify findings and methodically describe the exact anatomical location, providing additional supporting details to justify and support the diagnosis. Examples include mass effect on surrounding structures and sulci, midline cerebral shift, herniation of anatomy (and direction of herniation), and if a lesion is seen the size (in mm) and lesion outline (smooth, nodular, ring, irregular and contrast enhancing characteristics).

Marking criteria for the OSE

A statistical measure of the candidates' performance for the OSE normal/abnormal decision and detailed free text responses were statistically assessed against the expected answers by a first and second marker from the programme panel and the external examiner consultant radiologist.

Responses were classified as true positive (TP), true negative (TN), false positive (FP) or false negative (FN), using partial marks as described in a previous study.[16] All responses which indicated definitely normal were regarded as normal and scored TN or FP accordingly. All other responses were regarded as abnormal and scored as TP or FN. Resulting TP, TN, FP and FN fractions (whole and partial) were summed.

The marking criteria additionally allocated a points scoring system using a binary coding method for each abnormal case out of a possible total of 5 points, allowing a fractionated score to be given in the case of multiple abnormalities present, as applied in previous studies.[17] In free response answers where specific multiple abnormalities and locations were present the recording of these details has significance and potential to impact on patient outcomes, and affect the validity of the result. Correspondingly if individual elements of incorrect location or pathology were recorded or described as normal, points are reduced from the total possible score available.

Each normal case received one mark and an abnormal case had the opportunity of up to five marks awarded. Examples of mark distributions for an abnormal CT case are: Abnormal 1, Side: Right 1/4, Location: occipito-parietal lobe 1/4, Size: 26 mm × 20 mm 1/4, Mass Effect: effacement of local sulci 1/4, Oedema: minor surrounding oedema 1/4, Density: heterogeneous/mixed lesion 1/2, Contrast: hyper-dense irregular ring enhancement 1/4, Pathology: glioma 1, Differentials: metastasis 1.

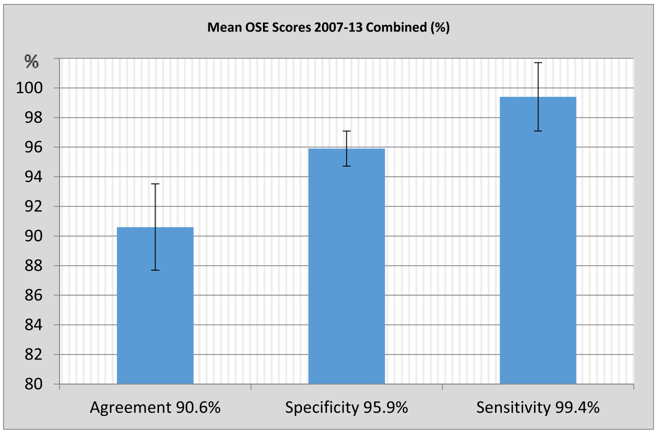
The final OSE total agreement, sensitivity and specificity were then calculated[13] for the candidate. Final radiographer scores were judged against a predetermined pass mark of 85% agreement and 90% sensitivity and sensitivity compared to the three independent radiologist reports.

It is well known that variation exists even between experience observers when interpreting medical images. When comparing the opinions of general radiologists and neuroradiologists in the

Table 1
Mean OSE scores from all cohorts combined (2007–13).

2007–13 All cohorts			
CT head scans	Mean%	95%CI	SD
Agreement %	90.6	88.1–90.8	7.14
Sensitivity %	99.4	97.4–99.8	5.65
Specificity%	95.9	93.1–99.8	2.89

Table 2
Bar chart of mean OSE scores from all cohorts combined (2007–13).



interpretation of CT neurological investigations, a literature search found a range of agreement levels including 66% (Briggs[18]), 84% (Schringer[19] and Nagaraja[20]), 86.6% (McCarron[21]), 95% (Erly[22]) and 97.3% (Le[23]) giving a mean average of 85.5% agreement from the published literature sources on consultant radiologist diagnostic performance. These published studies provide support for the appropriate performance level pass mark for the OSEs. No studies of CT head radiographer reporting could be identified precluding an established agreement level, only one study was identified by Craven[24] of one CT head reporting radiographer attainting a sensitivity level of 99.4% and specificity of 98.5% from 252 cases.

Results

Statistical analysis for each cohort of students in Table 1 detail the mean agreement scores for concordance, 95% confidence intervals (CI), and standard deviations (SD) in the reports ($n = 600$), in addition to comparisons of sensitivity and specificity scores.

The mean score, 95% CI and SD for all radiographer candidates ($n = 24$) from the summative assessment scores ($n = 600$ papers) shown in Tables 1 and 2, give a clear indication of the level of agreement, sensitivity and specificity of the ability of this small group of radiographers to interpret CT head examinations on patients referred from a range of different referral sources and with a number of pathological conditions. The highest mean agreement score determined for all cohorts was 90.6% (95% CI 88.1–90.8%). The mean sensitivity levels for all combined cohorts were 99.4% (95% CI 97.4–99.8%), the mean specificity figures for all cohorts combined were 95.9% (95% CI 93.1–97.7%) shown in Table 2. The highest mean individual cohort agreement rate demonstrated was 93%, the highest individual cohort sensitivity and specificity levels demonstrated were 100%.

Discussion

The candidates ($n = 24$) in all cohorts attained levels exceeding the pass rate for agreement (85%) and sensitivity and specificity rates of over 90% to successfully pass that component of the assessment. Illustrating that the radiographers were able to accurately distinguish and recognise all the abnormal examinations in the summative OSE.

Disagreements between the candidates and consultant radiologists in the interpretation and diagnosis of primary lesions occurred in an average of 9.4% of the total $n = 600$ reports. A mean 4.1% ($n = 600$) of these discordant cases occurred when the radiologists described them as normal and the radiographers as abnormal. The majority of cases arose where candidates reported small areas of infarction where the consultant radiologists identified no abnormality or no significant intracerebral abnormality. Among the majority of other discrepancies was a failure to record oedema or mass effect by both sets of observers (radiographers and radiologists).

Table 4 outlines in detail the pathological examples where the students had discordant details to the radiologists and the reduction of marks allocated. One of the most common conditions that failed to be recorded was perifocal oedema, which generated only a moderate level of concordance amongst the three independent consultant radiologists during the construction of the OSE bank. Helping to illustrate that the radiographers had an inclination to either under or over report the incidence of oedema. In addition Table 4 identifies a large proportion of incidental secondary findings that reduced the candidates' marks in abnormal cases. The failure to record additional incidental findings has been shown to apply to both sets of observers and exploration of this observable occurrence of cognitive and or perceptive error is well known in radiology.[25–31]

The clinical significance of this small finding against a rather large primary finding possibly would not have enough significance to potentially impact a change in therapy or outcome of the patient. The implications being the observer may have a penchant for over (misinterpreting findings/cognitive error[32,33]) or under reporting (missing lesions/perceptual error[34–36]) in multiple pathological cases.

Although the potential impact on patient outcomes can only at this stage be assumed, Fineburg[37] demonstrated that within hierarchical levels of clinical efficacy the use of CT head reports have direct influence on the referring physician's decisions in treatment plans, and thus the potential for error may have significant consequences. That is not to say that efficacy studies solely rely on reporting, it is but one part of a larger system of patient clinical examinations (blood tests, bacterial cultures, biopsies) that affect patient outcomes. Key points of the efficacy chart include the

Table 3
Mean OSE scores from individual cohorts.

CT head scans	2007–08 Cohort ($n = 5$)			2008–09 Cohort ($n = 7$)			2011–12 Cohort ($n = 6$)			2012–13 Cohort ($n = 6$)		
	Mean %	95%CI	SD	Mean %	95%CI	SD	Mean %	95%CI	SD	Mean %	95%CI	SD
Agreement %	87.5	86.18–88.82	1.51	90.1	87.0–93.2	4.18	91.7	89.26–94.14	3.05	93	91.77–94.23	1.542
Sensitivity %	100	~	0.00	97.7	94.81–100.59	3.9	100	~	0.00	93.5	90.99–96.01	3.14
Specificity%	96.6	93.55–99.65	3.48	93.5	91.17–95.83	3.15	100	~	0.00	98.4	95.38–101.42	3.78

Table 4
Common errors in interpretation by radiographers compared to reference standard.

Radiographer false positive/false negative	Expected answer
Subdural hematoma	Subdural hygroma
Periventricular small vessel disease	Normal or normal for age
Traumatic haemorrhage	Hematoma only
Subcortical ischemia	Normal or normal for age
Basal ganglia ischemia	Perivascular space
Ventriculomegaly	Volume effect
Tumor	Stroke
Lacunar infactions	Normal or normal for age
Perifocal oedema	Normal
Rasied intracranial pressure (Sulci effacment)	Normal
Herniation of cerebral contents	Mass effect

technical quality of the images which have the potential to affect reporting abilities,[38] the CT report, the post report effect on altered patient therapeutic plans to improve mortality/morbidity, and final patient outcomes including changes to or new treatments, avoidance of surgery or other diagnostic tests, hospital stay, or abandonment of clinical treatment.[17,39]

The mean agreement rate of 90.6% (95% CI 88.1–90.8%) achieved by the candidates, for normal and abnormal CT head examinations in this study also equates acceptably to the variance in concordance and major/minor discordance rates in studies by McCarron[21] and Erly.[22] These studies reported on a bank of similar cases, interpreted by radiologists to a reference standard and achieved similarly reported agreement rates between consultant radiologists of 86.6%–95%.

At present the data numbers are not adequately powered to determine recurrent discrepancies. A recent study by Mucci[40] argues that discrepancy in diagnostic reports, particularly interpretative and observational error is inevitable and scoring will always show poor interrater agreement, scoring in clinical practice is best scored against seriousness as advised by the RCR.[41]

Conclusions

In summary, the results presented here in Tables 1–3 answer both objectives that radiographers, at the completion of an accredited postgraduate reporting programme, can interpret cranial CT examinations with acceptable agreement, sensitivity and specificity under examination conditions in an academic setting. There also appears to be an insignificant variation between the mean agreement rates in comparison to similar studies of consultant radiologists reporting standards.[21,22]

Our results suggest in the academic environment the data demonstrates radiographers undertaking an approved course in CT head reporting have the potential to improve clinical service delivery. The authors acknowledge the limitations of low candidate numbers in the study which diminish sufficient comparison to the statistical power of larger similar studies. Further studies need to be completed in the future to examine the concordance and discordance levels of CT head reporting by qualified CT head reporting radiographers after a period of independent clinical practice to further investigate the potential contribution that CT head reporting radiographers can make to service delivery in the UK.

Conflict of interest statement

None.

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RESEARCH ARTICLE

CT sinus and facial bones reporting by radiographers: findings of an accredited postgraduate programme

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Objectives: The aim of this study was to compare the observer performance of a cohort of radiographers in reporting CT sinus and facial bone investigations against a reference standard and alternative comparator of summary data from peer-reviewed literature.
Methods: The participants ($n = 6$) completed a 9-month part-time distance learning training programme prior to reporting an examination bank ($n = 25$ cases) from a retrospectively collected and anonymized digital imaging and communications in medicine archive of CT examinations with referral histories and clinical reports. A literature search was performed to identify an additional alternative comparison reference standard from studies reporting observer performance data in CT sinus and facial bone investigations of both trauma and sinus pathology (target conditions). The data analyses used to measure observer performance and determine differences between the cohort and the reference standards used statistical assessment models including accuracy, sensitivity, specificity, kappa (κ) and summary receiver-operating characteristic curves with estimated area under the curve (AUC).
Results: The cohort of radiographer sensitivity was 97.5%, specificity 93.6% and accuracy 95%, with $p < 0.000$, and a $\kappa = 0.9121$ score of agreement. The mean radiographer AUC was 0.9822. The summary reported data of the alternative literature reference standard comparator were AUC 0.9533 for sinus and 0.9374 for trauma.
Conclusions: The results suggest that this cohort of radiographers at the end of a period training in CT sinus and facial bones are able to clinically report comparably high standards.
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Keywords: multidetector CT; radiography; paranasal sinuses; facial bones; radiology

Introduction

The use of functional endoscopic sinus surgery is a common surgical procedure within the UK National Health Service (NHS) to preserve mucociliary function and expand drainage routes of the paranasal sinus when medical treatment has failed to resolve symptoms. It has been evidenced that reliance on clinical examination alone is unreliable for diagnosis.[1,2] The inclusion of CT in the diagnostic pathway for sinus obstruction has been shown to alter treatment and management decisions through anatomical mapping and diagnosis of pathological disease.[1–3]

Likewise, in the initial diagnosis of maxillofacial trauma in the UK, CT is defined as the gold standard for cross-sectional imaging over MRI, owing to the ability to define bony anatomy (specifically infundibular complex, orbital lamina and cribriform lamina) and soft tissues.[4–7] In maxillofacial injuries, CT has been shown to have a high diagnostic value in diagnosing traumatic injuries that initial clinical assessment may have missed owing to associated soft-tissue swelling of the surrounding anatomy,[8,9] providing quick initial examination of osseous and soft-tissue injuries and further associated deep tissue injuries that may involve the facial and optic

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nerves, muscles, glands, sinuses and cranial injuries.[8] The evidence to further support the use of CT in the UK maxillofacial trauma pathway has included speed of examination,[10] and the cost effectiveness to image and report the examination against its next nearest viable imaging modality. In the UK healthcare system, the economic costs of services are regulated by the Department of Health through NHS England (the executive non-departmental government body) to standardize all healthcare costs in the NHS. The 2016–17 tariff for a CT facial bone scan and reporting was £78 + £22, as opposed to an MRI scan and reporting of £124 + £22.[11] For patient health and safety reasons, and to reduce the potential risk of harm in imaging patients who are unconscious or sedated with no clinical history, CT is recommended as the first-line investigation in facial trauma as opposed to MRI, through the National Institute for Health and Care Excellence guidelines.[12]

The UK NHS service delivery evidence for implementing reporting radiographers (RRs) has been demonstrated by a recent UK Royal College of Radiologists (RCR) survey[13] highlighting the current demand (29% rise in patient referrals for CT 2014–15)[13] and capacity (radiologist workforce shortages) issues in UK radiology. The RCR estimated 230,000 patients in 2016 were waiting too long for diagnostic reports (over 31 days); 12,178 of these included CT and MRI scans.[14] The evidence revealed 75% of English NHS trusts had a backlog of reporting.[14] The estimated cost in the short term to reduce the backlog in 2015 was £88.2m, an increase of 57% from the previous year, through outsourcing to private telereporting companies.[14] The RCR consider this cost to be equivalent to 1032 NHS consultant radiologist salaries.[13] A recent NHS England report[15] reviewed the effect of outsourcing had been unsuccessful not only owing to high costs, but clinicians had limited access to discuss complex cases with private providers/reporters leading to unnecessary repeat imaging, which further increased the reporting demand. NHS England[15] highlighted the impact the workforce deficit had on diagnostic services as a significant bottleneck in the system. NHS England[13] recommended the workforce restrictions need addressing through multiple national initiatives to resolve the low number of reporters. One long-term plan to achieve sustainable and economic solutions to the sector supported by the Department of Health,[16] the Society and College of Radiographers and the RCR[17] is the introduction of a skills mix of radiographer and radiologist teams working in reporting, funded in part by NHS England[18] with a £15m 4-year initial investment to support early and fast reporting through a "National Diagnostics Capacity Fund", with plans to finance amongst other areas an increase of radiographers and radiologists to improve patient outcomes.

The UK healthcare system definitions of the role of a consultant radiologist working in the NHS are set by the RCR. This clinical role is described as performing examinations and procedures in complex diagnostic and therapeutic imaging investigations and interventions, and the reporting of medical images in trauma, disease and cancer.

The UK healthcare role of a diagnostic radiographer (commonly known globally as a radiologic technologist, or medical radiation technologist) has a very diverse career pathway and differs slightly from other foreign healthcare systems, although there is common scope of practice in the role globally, which includes imaging of the human anatomy, enforcement of radiation protection, justification of examinations and patient care. In the UK NHS, there are many subspecialities defined by the different imaging modalities, and each has role extension and advanced practice routes to consultancy level through master education. Within this study, the role of the RR is explored. Since 1994, the UK NHS has developed and implemented RRs to analyze, interpret and write the final examination report on a range of plain film, mammography, CT, MRI and nuclear medicine examinations. It is noted that other countries such as the Republic of Ireland, Finland, Norway, Australia, New Zealand and South Africa have also been developing and embedding RR roles for some years within their healthcare systems that is similar to the UK approach.

The postgraduate reporting course in CT sinus and facial bones in this study was accredited by the UK College of Radiographers in 2011. The course runs consecutively with the postgraduate certificate in CT head reporting, as a part-time work-based module (20 credits at Level 7) over a period of 9 months. The curriculum and teaching were developed jointly by consultant radiologists and RRs. The assessment criteria for the module include a written case study, a record of a minimum of 125 clinical reports and an objective structured examination (OSE).

The aim of this study was to investigate primarily whether a cohort of radiographer accuracy level in CT reporting of sinus and facial bone examinations is equal or equivalent in comparison with a radiologist performance level after a period of training (academic and clinical). This will be measured through the analysis of OSE results of the participants who have completed the programme ($n = 6$) against the defined OSE radiologist reference standard, accompanied by an exploration of the relationship between the Student's t-test performance against an alternative comparator (the published results from peer-reviewed literature in CT sinus and facial bone observer performance by radiologists).

Methods and materials

Ethics

This study has received ethics and governance approval agreed by the Faculty of Health and Wellbeing Research Ethics Committee.

Assessment of observer performance

The programme of study adhered to the postgraduate pathway of assessments for the clinical reporting modules at our university, with a final assessment of competence through an OSE, consisting of 25 adult (>18 years) retrospective CT sinus and facial bone cases (index test) under controlled examination conditions,[19] using low-level lighting and high-definition reporting monitors[20] that adhere to RCR reporting standards[21] (42 cm, 1280 × 1084 screen resolution, $>170\,\text{cd}\,\text{m}^{-2}$ luminance, ≥250 : 1 luminance contrast ratio). The CT studies were presented in digital imaging and communications in medicine format on KPACS software (Image Informations Systems Ltd, London, UK)[22] to allow manipulation by the reader.[21]

Reference standard

A retrospectively collected and anonymized digital imaging and communications in medicine archive of CT sinus and facial bone examinations with referral histories (gender, age, clinical symptoms and previous medical history) and clinical reports was used in the construction of the OSE examination. Each case was independently reported by three consultant radiologists (each blinded to the original report, to minimize verification and work-up bias). The reference standard report for each examination was established through review and consensus of the three consultant radiologist[23] reports by the programme panel and external examiner (independent consultant radiologist). This process verified that an appropriate range of target conditions (and diagnostic thresholds) was incorporated to reflect the postgraduate-level knowledge and competence. The test banks contained negative cases (48%) and subtle and characteristic positive (single site and multisite) pathological cases (disease prevalence 52%).

Target conditions

In the paranasal sinus cases, positive target conditions included: the presence of soft-tissue lesions, polyps, retention cysts and mucoceles; obstruction of the mucociliary drainage (ostium, ostiomeatal complex, infundibulum and middle meatus); and moderate mucosal changes (without fluid or opacification signs). Disease distribution of diffuse mucosal thickening was shown in multiple sinuses (unilateral or bilateral) such as rhinosinusitis (short-term symptomatic inflammation of the nasal cavity and paranasal sinus) and sinusitis inflammation of a single sinus cavity. In addition, secondary pressure effects of destruction, sclerosis or decalcification of the bony sinus walls from adjacent lesions and/or post-surgical interventions were included. Normal variants (to reduce spectrum bias) such as a deviated nasal septum, concha bullosa, paradoxical curvature of middle turbinates, uncinate bulla, onodi cells, hypoplastic frontal sinus, Haller cells, bulla ethmoidalis, posterior nasal septal air cells, *agger nasi* cells (not causing mechanical obstruction of frontal recess area) and aerated crista galli seen in isolation were deemed normal in this study.

For the facial bones, target cases included examples of orbital blowout fractures, complex midface injuries with multiple osseous fractures (including Le Fort I, II and III), mandibular fractures, orbital trauma, associated soft-tissue emphysema, muscle, dental complications and herniated bone fragments. Normal variants for the facial bone cases included sutures, fissures, artefacts of partial-volume averaging and dental/ocular implants.

Index test

The scans were presented in standard CT protocols with a slice thickness of 3–5 mm coronal, axial and sagittal data sets. The volume data were reconstructed into adjustable bone (window width 2000 HU and window level 450 HU) and soft-tissue (window width 400 HU and level 50 HU) algorithms. The use of axial, coronal[8] and sagittal[24,25] CT reconstructions allowed the radiographers to review the triplanar (horizontal, sagittal and coronal) osseous struts[8] for trauma, and the coronal views to approach the osteomeatal unit in paranasal sinus examinations.

Study population

The six RRs 1–6 were provided with the referral clinical symptoms, including gender, age (18–92 years) and the referral source (accident and emergency, general practitioner, in-patient and out-patient). The sampling method and inclusion criterion of the population in this observer performance test were randomly selected in both frequency and severity of target conditions. It was acknowledged that the patient history for CT sinus investigations could be deemed misleading, as age and gender distribution of cases has been evidenced to be inconsistent with pathological distribution. The correlation between symptoms of pain, tenderness, pressure, congestion, discharge, headache, dysosmia, anosmia/hyposmia and nasal blockage does not always associate to normal/abnormal findings.[26–28]

Test bank instructions

The candidates were asked to decide whether the examination was normal or abnormal and provide a detailed report of findings (describing the exact anatomical location) in a free-text response, including the primary condition and any secondary mass effects. When identifying and classifying abnormal sinus appearances, details of the soft-tissue disease such as localized thickening of the wall, hypertrophic mucosa or focused opacification of the sinus (singular or in combination/expansion into adjoining sinus) were used. The presence of horizontal fluid levels within a sinus cavity, or if a lesion was seen, the size (in millimetre) and lesion/fluid characteristics (with associated bone erosion/destruction/extension in sinuses) was required.

The participants in this programme were not taught the Lund–Mackay system,[29,30] although it has been widely adopted by others such as the American Academy of Otolaryngology as a system for pre-operative planning for chronic rhinosinusitis. Although it has scored better than other CT staging systems for chronic sinusitis (such as Jorgensen, May and Levine, Newman,[31] Kennedy and Harvard),[32] the Lund–Mackay system[28]

Table 1 Summary reporting radiographer (RR) 1–6 observer performance results from the objective structured examination

						Accuracy		*Sensitivity*		*Specificity*		*Fisher's test*
RRs	*Number of cases*	*TP*	*TN*	*FP*	*FN*	*Accuracy*	*95% CI*	*Sensitivity*	*95% CI*	*Spec*	*95% CI*	p-*value*
RR 1	25	12	11	1	1	0.920	0.701–0.993	0.923	0.640–0.998	0.917	0.615–0.998	0.000
RR 2	25	13	11.5	0.5	0	0.980	0.778–0.980	1.000	0.753–1.000	0.958	0.672–1.000	0.000
RR 3	25	13.5	10	1	0.5	0.940	0.727–0.980	0.964	0.712–1.000	0.909	0.587–0.998	0.000
RR 4	25	11.5	12	1	0.5	0.940	0.725–0.980	0.958	0.672–1.000	0.923	0.640–0.998	0.000
RR 5	25	15	9	1	0	0.960	0.755–0.960	1.000	0.782–1.000	0.900	0.555–0.997	0.000
RR 6	25	13	12	0	0	1.000	0.805–1.000	1.000	0.753–1.000	1.000	0.735–1.000	0.000
Mean						0.950	0.733–0.982	0.975	0.913–0.997	0.936	0.851–0.980	0.000

CI, confidence interval; FN, false negative; FP, false positive; TN, true negative; TP, true positive.

has been shown not to be a significant predictor to influence patient outcomes[1,32] and as such was not adopted as the candidates were also required to comment on the non-sinus facial anatomy as well.

Statistical analyses

Responses were classified as true positive (TP) and true negative (TN) for correct answers and false positive (FP) or false negative (FN) for incorrect answers, with the use of fractions (whole and partial) as described in a previous study.[33] Each examination paper was triple reviewed for concordance of marks, by two academics and an external examiner (consultant radiologist), to verify an accurate and fair marking process was followed inline with the established reference standard reports. Sensitivity, specificity and accuracy were calculated using standard measures of observer performance using a 2 × 2 contingency table,[34] with Fisher's exact test (displaying two-tailed *p*-value owing to the small sample size). Mean values were further estimated, and interobserver variation was observed using Cohen's kappa (κ) to correct for chance agreement,[19] with Fleiss' kappa (κ) for multiple reader reliability agreement with 95% confidence intervals (CIs) and standard error. Further review using positive-predictive value and negative-predictive value was run to evaluate the performance of the reader influenced by the disease prevalence of the test. Likelihood ratios to assess the value of performing the test (not disease prevalence dependent). Diagnostic odds ratios as a global measure of RR 1–6 diagnostic accuracy (not disease prevalence dependant, but reliant on the spectrum of the target conditions used). Summary receiver-operating characteristic (ROC) curves were plotted with the area under the curve (AUC) estimated for the discriminative power of the observers between the target conditions and negative cases.

Alternative comparator

A literature search was performed to identify an alternative comparison reference standard from studies reporting observer performance data in CT sinus and facial bone examinations (index test) for both trauma and sinus pathology (target conditions). The search used the Cochrane Central Register of Controlled Trials (CENTRAL) (the Cochrane Library October 2016, Issue 10) and the following databases from 1995 to 2016: MEDLINE, CINAHL and PubMed Central, while also conducting search through subject-specific electronic databases (ScienceDirect and Wiley Online) and Google Scholar. Further studies were identified for possible inclusion through review of reference lists from studies found in the initial search. Free-text words and Boolean operator search terms were included to identify specific and exact matches. Selection criteria included reviews of all cohort studies that used CT imaging as the index test for the target conditions. The patient population was defined from either a clinical examination or clinical diagnosis, and from a predefined radiological reference standard report in the study method. All observer groups included radiologists; two also included maxillofacial surgeons as readers. The published study data either defined the results in TP, FP, TN and FN or were derivable from data within the published study (such as sensitivity, specificity and accuracy). It was noted from the preliminary review of the published studies that no control group was included in the studies, but all had a defined reference standard to fulfil the criteria for acceptance. Found studies were reviewed for methodological quality against the Quality Assessment

Table 2 Summary reporting radiographer (RR) observer performance results from the objective structured examination

		Cohen's kappa			*Cohen's kappa*			*Fleiss' kappa*		
RRs	*Number of cases*	*Unweighted* κ	*95% CI*	*SE*	*Linear Weighted* κ	*95% CI*	*SE*	κ	*95% CI*	*SE*
RR 1	25	0.8397	0.6267–1.000	0.1087	0.8397	0.6266–1.000	0.1087	0.840	0.627–1.000	0.109
RR 2	25	0.9599	0.8498–1.000	0.0562	0.9599	0.850–1.000	0.0561	0.960	0.882–1.000	0.040
RR 3	25	0.8777	0.6879–1.000	0.0969	0.8777	0.6881–1.000	0.0967	0.878	0.744–1.000	0.068
RR 4	25	0.8800	0.6938–1.000	0.095	0.8800	0.694–1.000	0.0949	0.880	0.748–1.000	0.067
RR 5	25	0.9153	0.7526–1.000	0.083	0.9153	0.7532–1.000	0.0827	0.915	0.753–1.000	0.083
RR 6	25	1.000	1.000–1.000	0.000	1.000	1.000–1.000	0.000	1.000	1.000–1.000	0.000
Mean		0.8924	0.7131–1.000	0.0909	0.8998	0.7131–1.000	0.0909	0.9121	0.721–1.000	0.0611

CI, confidence interval; SE, standard error.

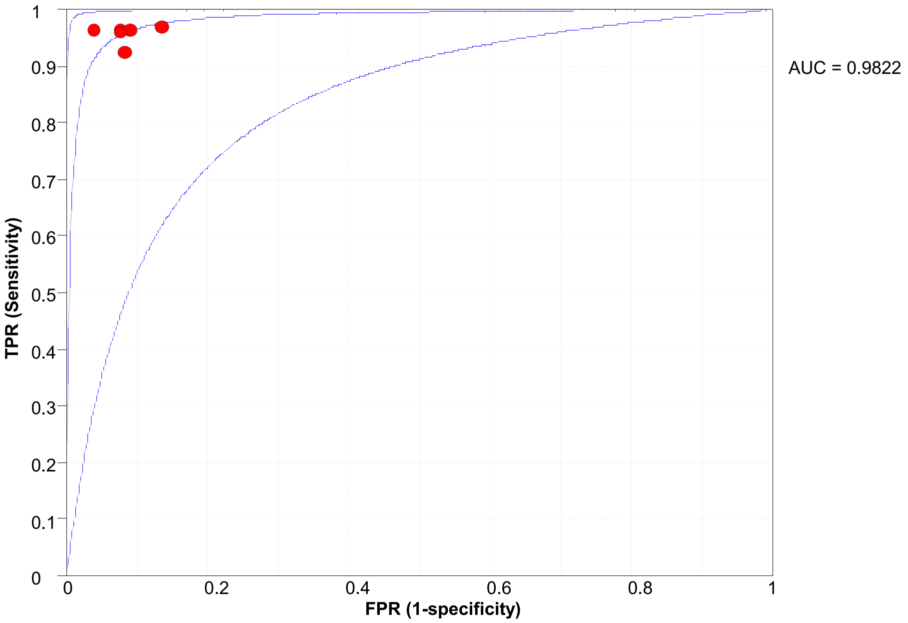


Figure 1 Summary receiver-operating characteristic curve of plots of the range of reporting radiographer 1–6 observer performance from the objective structured examination. AUC, area under the curve; FPR, false-positive rate; TPR, true-positive rate.

of Diagnostic Accuracy Studies (QUADAS-2) criteria.[35] There was minor variation in methods to display the results and therefore, where possible, reanalysis of the published data to conform to standard 2 × 2 contingency table. The analysis was performed using Cochrane Diagnostic Test Accuracy review software (Review Manager (RevMan) The Cochrance Collaboration, Copenhagen: Denmark)[36] and Meta-DiSc software (Unit of Clinical Biostatistics, Ramóny Cajal Hospital, Madrid: Spain).[37] Sensitivity and specificity were confirmed from the published data and displayed in a standardized interpretation model of forest plots as a graphical representation of the results of multiple trials and studies of the same intervention, with standardized interpretation model meta-analysis of results using pooled estimates, χ^2 with p-values (large sample distribution) and inconsistency (I^2) to identify any heterogeneity or consistency of results, with degrees of freedom. Summary ROC curve plots were used to assess and illustrate the performance (discrimination threshold) through plotting the true-positive rate and false-positive rate of the range of multiple published results, and a summary AUC was calculated.

Results

Observer performance

The mean RR 1–6 sensitivity was 97.5% (95% CI 91.3–99.7), specificity 93.6% (95% CI 85.1–98) and accuracy 95% (95% CI 73.3–98.2), with significance of $p < 0.000$, as shown in Table 1. The mean RR 1–6 κ values for observer performance across all test banks combined (Cohen's κ = 0.8924, 95% CI 71.3–100, and Fleiss' κ = 0.9121, 95% CI 72.1–100) displayed a high κ score of agreement (Table 2). The mean RR 1–6 AUC was 0.9822 (plotted in Figure 1); the summary random effects model is displayed in Table 3.

Table 3 Summary random effects model of reporting radiographer (RR) 1–6 observer performance results from the objective structured examination

		PPV		*NPV*		*+LR*		*Negative likelihood ratio*		*DoR*	
RRs	*Number of cases*	*PPV*	*95% CI*	*NPV*	*95% CI*	*+LR*	*95% CI*	*−LR*	*95% CI*	*DoR*	*95% CI*
RR 1	25	0.923	0.712–0.993	0.917	0.688–0.993	11.077	1.685–72.816	0.084	0.013–0.556	132.00	7.336–2375.2
RR 2	25	0.963	0.776–0.963	1.000	0.780–1.000	12.536	1.902–82.629	0.039	0.003–0.591	324.00	9.555–10,545.3
RR 3	25	0.931	0.747–0.966	0.952	0.698–1.000	10.607	1.632–68.924	0.039	0.003–0.601	270.00	8.220–8868.8
RR 4	25	0.920	0.705–0.960	0.960	0.745–1.000	12.458	1.888–82.200	0.045	0.003–0.684	276.00	8.420–9047.0
RR 5	25	0.938	0.778–0.938	1.000	0.716–1.000	7.104	1.601–31.516	0.036	0.002–0.559	196.33	7.235–5328.1
RR 6	25	1.000	0.812–1.000	1.000	0.796–1.000	25.071	1.652–380.54	0.037	0.002–0.566	675.00	12.428–36,659.7
Mean		0.943	0.741–0.967	0.917	0.724–1.000	10.858	5.060–23.299	0.049	0.018–0.137	249.72	62.463–998.35

+LR, positive likelihood ratio; −LR, negative likelihood ratio; CI, confidence interval; DoR, diagnostic odds ratio; NPV, negative-predictive value; PPV, positive-predictive value.

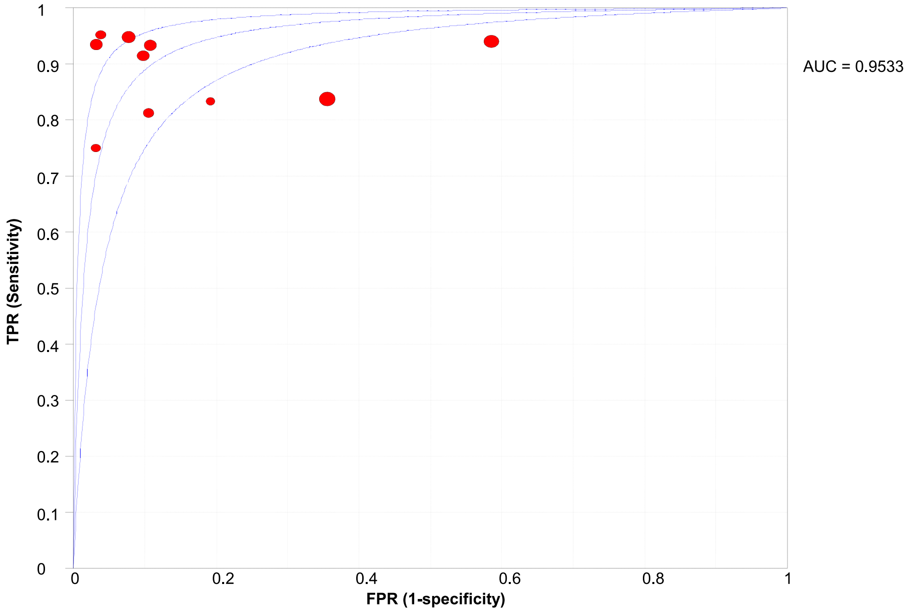


Figure 2 Summary receiver-operating characteristic curve plots of the range of observer performance from published literature results in CT sinus studies. AUC, area under the curve; FPR, false-positive rate; TPR, true-positive rate.

Alternative comparator

For the literature review results, 10 studies were found ($n = 847$ sample size in total) for the CT sinus observer performance studies. 11 studies were identified (including $n = 2428$ sample size in total) for CT facial bones observer performance studies. The methodological quality of these studies was satisfactory for inclusion in this study. However, it is noted there is the potential for bias in certain studies related to the anatomical area of the facial bones/sinus reviewed for focused target conditions. Results shown in ROC plots displayed in Figure 2 a mean AUC of 0.9533 (sinus target conditions) and Figure 3. Mean AUC 0.9374 (trauma target conditions) as an alternative comparator to the RR 1–6 AUC of 0.9822 (Figure 1). In Figure 4, a forest plot demonstrates the alternative comparison sensitivity estimate of 90% (95% CI 87–92) and in Figure 5, specificity of 78% (95% CI 73–82) for CT sinus observer performance,

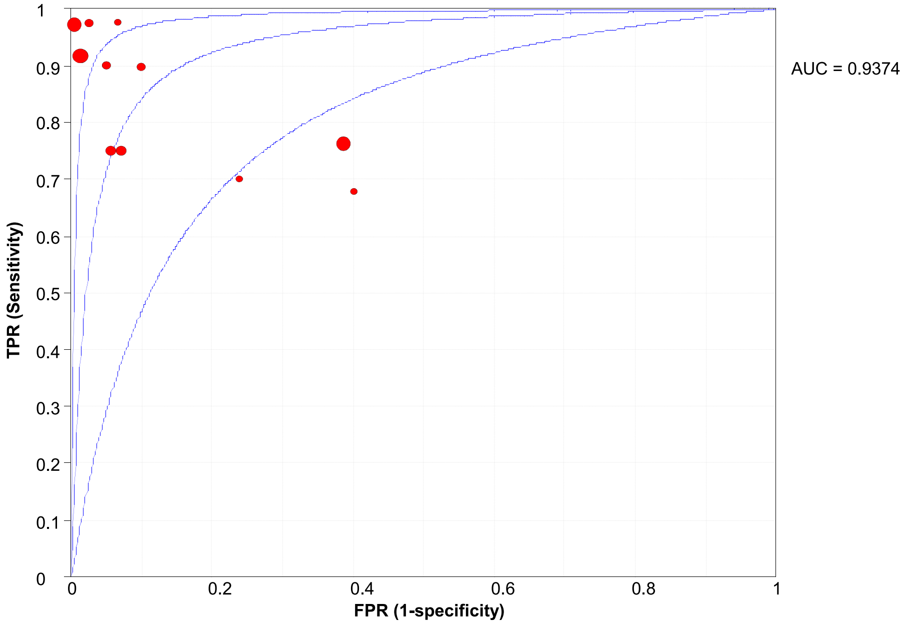


Figure 3 Summary receiver-operating characteristic curve plots of the range of observer performance from published literature results in CT trauma studies. AUC, area under the curve; FPR, false-positive rate; TPR, true-positive rate.

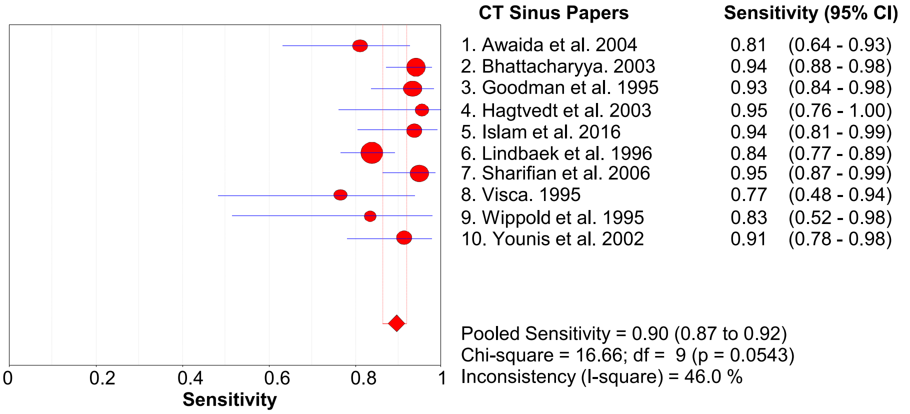


Figure 4 Forest plot of observer sensitivity performance from published literature in CT sinus studies. CI, confidence interval.

with a similar sensitivity estimate of 87% (95% CI 85–89) in Figure 6 and specificity of 89% (95% CI 87–91) in Figure 7, for CT facial bones as an alternative comparator for the RR 1–6 results. The available literature evidence base when used in comparison with this cohort study suggests the students could diagnose target conditions with a high degree of confidence.

Discussion

The main findings of the RR 1–6 performance in CT sinus and facial bone reporting display a high degree of sensitivity, specificity and accuracy to the reference standard and current evidence base when assessed in an academic setting. Discordance of participant reports included minor FP error over the degree of mucosal thickening required to confirm chronic sinus conditions in a case referred for other conditions. This raises the issue of incidental findings in CT examinations of patients who are asymptomatic, giving FP results which previous studies have quoted various FP ranges of 2.1[38]–5.2%.[39] Moreover, studies have questioned whether minor mucosal thickening of 4–5 mm has any clinical significance and may be related to normal variance or function of the physiologic nasal cycle, and not correlated to allergic seasonal variance.[40] A further FP case involved a case of correct diagnosis of complete sinus opacification of the maxillary antrum, but queried whether there was an underlying lesion associated. Although, in this instance, there was no mixed signal density of the fluid or associated bony erosion or remodelling, it does raise the issue of correct identification of disease in a fluid-filled sinus cavity which may mask the underlying polyposis, lesion or a retention cyst.

Common satisfaction of search errors included FN errors of adjacent or additional conditions including deossification of ethmoid septa from bordering nasal polypi and small areas of further mucosal thickening in adjacent sinuses, and also an FN error of a small orbital floor herniation into the maxillary antrum in a case of complex facial trauma involving Le Fort III fractures.

Within facial injuries, Le Fort[41] described and detailed facial trauma patterns to a standard that is still used today to classify the various possible traumatic bone fracture patterns to the structural pillars of the facial skeleton. Limitations of this system include the lack of associated soft-tissue injury identification, which may involve multiple anatomical areas with varying degrees of significance including orbital, sinus, nerve and

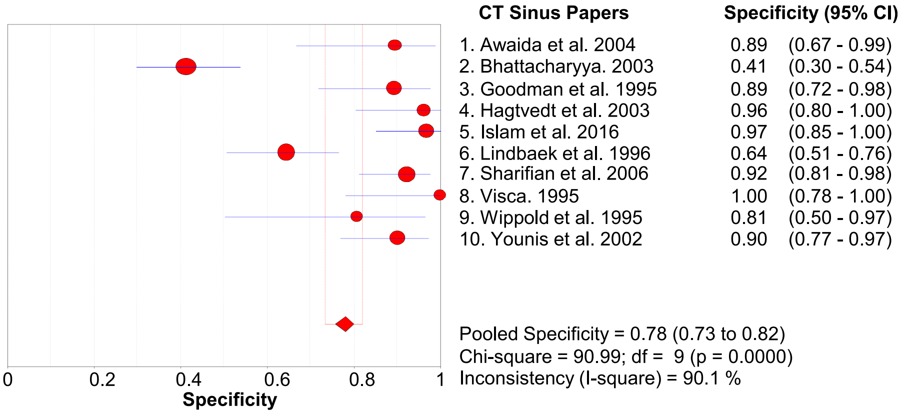
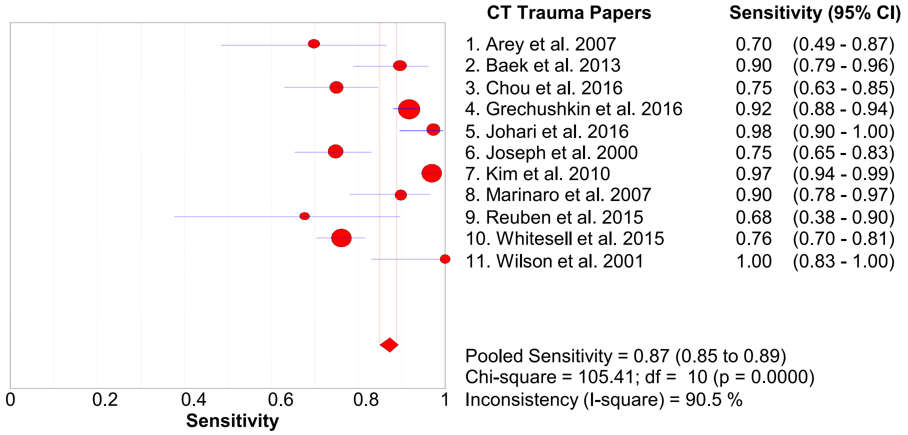


Figure 5 Forest plot of observer specificity performance from published literature in CT sinus studies. CI, confidence interval.



CT Trauma Papers	Sensitivity (95% CI)
1. Arey et al. 2007	0.70 (0.49 - 0.87)
2. Baek et al. 2013	0.90 (0.79 - 0.96)
3. Chou et al. 2016	0.75 (0.63 - 0.85)
4. Grechushkin et al. 2016	0.92 (0.88 - 0.94)
5. Johari et al. 2016	0.98 (0.90 - 1.00)
6. Joseph et al. 2000	0.75 (0.65 - 0.83)
7. Kim et al. 2010	0.97 (0.94 - 0.99)
8. Marinaro et al. 2007	0.90 (0.78 - 0.97)
9. Reuben et al. 2015	0.68 (0.38 - 0.90)
10. Whitesell et al. 2015	0.76 (0.70 - 0.81)
11. Wilson et al. 2001	1.00 (0.83 - 1.00)

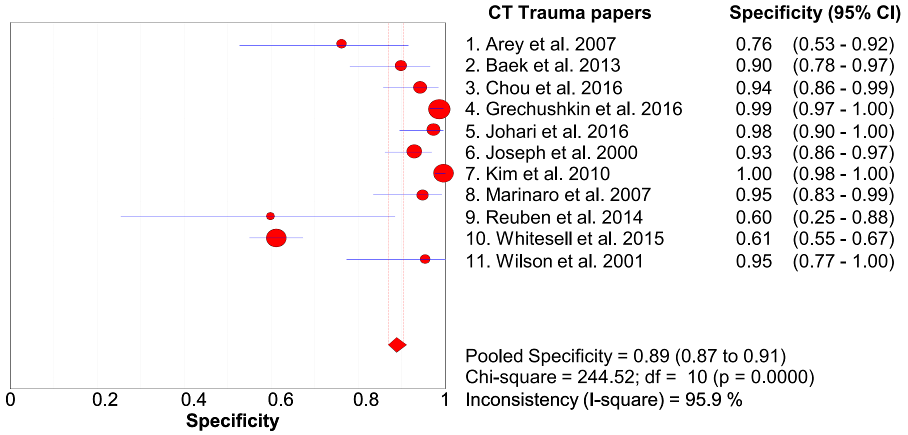
Pooled Sensitivity = 0.87 (0.85 to 0.89)
Chi-square = 105.41; df = 10 (p = 0.0000)
Inconsistency (I-square) = 90.5 %

Figure 6 Forest plot of observer sensitivity performance from published literature in CT facial trauma studies. CI, confidence interval.

ligamentous involvement, in the diagnosis of unstable fractures primarily with anterior or lateral displacement which may involve further injuries such as sagittal fractures of the maxilla and palate.[42] Although uncommon, they alter management owing to the significant instability and surgical management required to reduce and fixate the fragments. Indeed, any maxillofacial trauma has the potential for disfigurement, disability and facial nerve damage which can significantly alter patient treatment and management.

Gentry et al[8,43] advise the use of axial and coronal CT reconstructions for facial trauma interpretation, which allows for specific search patterns of the facial struts. The horizontal, sagittal and anterior coronal struts (perpendicular to each other) allow compartmentalization of maxillofacial anatomy into oral, nasal, paranasal and orbital zones, enabling identification of osseous injuries and the structural attachments of facial and extraocular muscles and soft-tissue structures,[43] being particularly useful in structures such as the cribriform plate, hard palate, vomer, alveolar ridge and pterygopalatine fossa, which may give rise to FN reports if not reviewed thoroughly. The Gentry et al[8] system is similar to various other search patterns such as the Buttress system (four transverse and vertical buttresses) by Hopper et al[44] used for midface trauma, which has a correlation to more significant and life-threatening outcomes. Essentially, Gentry et al[8] advise the coronal and axial planes as ideal for reviewing the facial structures. For this study, we also supplied sagittal plane reconstructions, as it supported diagnosis for herniation of structures, which allowed additional supplementary evidence of traumatic injuries to the orbital floor, malar strut, maxillary wall displacement, zygomaticomaxillary fractures and frontal sinus anatomy.[24,25]

These evaluation findings have the potential for impact beyond academia, by embedding this defined scope of practice into radiographer advance practice roles. It is hoped future studies will determine the impact and outcomes of this research in conjunction with other RR work to reduce reporting backlogs, in comparison with nationally evidenced delays.[14] In addition, it has been previously reported that radiographers are an economical and viable option in CT reporting,[45] and further review would be beneficial given the current NHS financial restraints. The impact of this study is to



CT Trauma papers	Specificity (95% CI)
1. Arey et al. 2007	0.76 (0.53 - 0.92)
2. Baek et al. 2013	0.90 (0.78 - 0.97)
3. Chou et al. 2016	0.94 (0.86 - 0.99)
4. Grechushkin et al. 2016	0.99 (0.97 - 1.00)
5. Johari et al. 2016	0.98 (0.90 - 1.00)
6. Joseph et al. 2000	0.93 (0.86 - 0.97)
7. Kim et al. 2010	1.00 (0.98 - 1.00)
8. Marinaro et al. 2007	0.95 (0.83 - 0.99)
9. Reuben et al. 2014	0.60 (0.25 - 0.88)
10. Whitesell et al. 2015	0.61 (0.55 - 0.67)
11. Wilson et al. 2001	0.95 (0.77 - 1.00)

Pooled Specificity = 0.89 (0.87 to 0.91)
Chi-square = 244.52; df = 10 (p = 0.0000)
Inconsistency (I-square) = 95.9 %

Figure 7 Forest plot of observer specificity performance from published literature in CT facial trauma studies. CI, confidence interval.

supplement the growing evidence base of RRs outside of plain film reporting and into cross-sectional modalities[33,46] to support service delivery and patient outcomes. It has been previously shown[47] that multimodality radiographer reporting can influence and benefit patient treatment and management to improve outcomes and care, which is a major factor in advancing the role development of radiographers in healthcare systems both nationally and internationally.

Limitations

A weakness of the literature review included the relatively small number of identified studies and sample size within each study (index tests and observers). It was noted that the literature on this subject is low, and therefore this will impact upon the results to be generalizable. Another significant weakness to identify is the heterogeneity identified in found literature, of which some focused on individual anatomical areas or specific target conditions. In addition, the author recognizes that this review of found literature reanalyzed the published data according to standard 2 × 2 contingency table to confirm its results. Although other models do exist, it was deemed beyond the scope of this review to discuss the statistical grounds for recommendations of different interpretation models.

Given the risk of bias and heterogeneity of found studies, an opinion could be made for not providing a review of these results to the found literature. However, it was believed that additional value was gained from it, despite limitations from the limited published research in this clinical area.

Conclusions

In this study, the overall aim was to investigate the performance of a group of radiographers at the end of an accredited postgraduate programme in clinical reporting of CT sinus and facial bone investigations. The results displayed high levels of agreement when compared with the OSE reference standard. The evaluation and comparison of results with the published literature using standardized interpretation models suggest this cohort of participants can report selected CT investigations with satisfactory accuracy under examination conditions in an academic setting. The conclusions that can be reached from this preliminary study are limited by the method and sample size. However, the collaboration and integration of skills mix reporting for the benefit of patient outcomes have previously been shown in other reporting modalities, and it may also benefit CT sinus and facial bone reporting in the future. The impact of the data from this study could help increase the evidence base of advanced practice roles, although it is restricted currently to the defined roles available to UK radiographers. This may not be at present be globally generalizable to other healthcare systems; it is noted other countries are developing and implementing RR roles to benefit service provision through healthcare improvement initiatives.

Recommendations from this study include further research on a large cohort of radiographers within a clinical practice environment to allow consensus on the results. Recommendations for RRs within this area include adherence to an agreed scheme of work, routine governance, regular audit and continuing professional development to support advanced practice roles.

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Research Article

Observer Performance in Computed Tomography Head Reporting

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ABSTRACT

Aim: To audit the reporting results of a cohort of radiographers ($n = 6$) completing an accredited academic program in clinical reporting of computed tomography (CT) head examinations.

Methods: An audit of retrospective academic image case banks and prospective random clinical workload case banks. Both the academic test banks and clinical workload banks included a wide range of normal and abnormal cases of different levels of difficulty and pathology. Abnormalities included hemorrhage, fractures, lesions, infarctions, degeneration, and normal variants from a variety of referral sources. True positive and negative, as well as false positive and negative fractions were used to mark the reports, which were analyzed for accuracy against a reference standard. Furthermore, interobserver variability was assessed using Cohen's kappa, one-way analysis of variance, and Tukey for multiple comparisons and significance testing at 95% confidence intervals (CI).

Results: The mean accuracy score for all radiographers ($n = 6$) and reports ($n = 3{,}008$) was 90.7% (95% CI, 88.3%–93.0%). Mean sensitivity and specificity rates were 86.9% (95% CI, 85.8%–88.2%) and 94% (95% CI, 89.6%–98.3%), respectively. The most common errors were associated with herniation, lacunar infarctions, and subtle fractures (false negatives) and involutional changes, subtle infarctions, and ventricular dilation (false positives).

Conclusions: The results suggest appropriately trained radiographers can successfully undertake to report computed tomography head examinations to a high standard. The adoption of both academic and clinical workload image banks that reflect disease examples and the prevalence that may logically be encountered in practice offers the potential for an accurate measure of performance of radiographer's abilities.

RÉSUMÉ

But : Faire une vérification des résultats présentés par une cohorte de radiographes (n=6) qui terminent un programme d'études agréé en présentation clinique des résultats d'un examen de la tête par tomodensitométrie (TDM).

Méthodologie : Vérification des banques d'images académiques rétrospectives et de cas randomisées de charge de travail clinique. La banque d'images académiques et la banque de charge de travail clinique contiennent toutes deux un large éventail de cas normaux et anormaux présentant différents niveaux de difficulté et de pathologie. Les anomalies comprennent des hémorragies, des fractures, des lésions, des infarctus, de la dégénérescence et des variations normales provenant de différentes sources de référence. Des vrais positifs et des vrais négatifs, des faux positifs et des fractions négatives ont été utilisés pour noter les rapports, dont l'exactitude a été analysée par rapport à une norme de référence. La variabilité entre les observateurs a été évaluée au moyen du coefficient Kappa de Cohen, de l'analyse de variance à un critère et de l'algorithme de Tukey pour permettre des comparaisons multiples et un test de signification avec des intervalles de confiance de 95%.

Résultats : La note d'exactitude moyenne pour l'ensemble des radiographes (n=6) et des rapports (n=3 008) a été de 90,7% (IC 95% 88,3 %-93,0%). La sensibilité moyenne et le taux de spécificité étaient respectivement de 86,9% (IC 95%: 85,8 %-88,2%) et de 94% (IC 95%: 89,6 %-98,3%). Les erreurs les plus communes touchaient les hernies, les infarctus lacunaires et les fractures subtiles (faux négatifs) ainsi que les changements involutifs, les infarctus subtils et la dilation ventriculaire (faux positifs).

Conclusions : Les résultats donnent à penser que des radiographes bien formés sont en mesure de préparer des rapports sur les examens de la tête par TDM selon une norme élevée. Le recours à des banques d'images académiques et de charge de travail clinique reflétant des exemples de maladies et la prévalence qu'on peut logiquement s'attendre à trouver dans la pratique peuvent permettre une mesure exacte du rendement et des aptitudes des radiographes.

Keywords: Reporting radiographer; computed tomography; image interpretation; diagnostic accuracy

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The authors declared no conflicts of interest.

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Introduction

Demand for computed tomography (CT) examinations in English National Health Service (NHS) Trusts between March 2015 and February 2016 [1] approximated 5,007,188 examinations. For the month of February 2016 alone, there were 104,667 on the waiting list, 37,734 planned tests, and 126,500 unscheduled tests [2]. The NHS Imaging and Radiodiagnostic activity report [3] assessed the number of CT investigations between April 2013 and March 2014 at 5.2 million. Demonstrating a 10% increase from the previous year [3], a 43.1% rise over 5 years [4] and 160% growth over a decade [3]. The Centre for Workforce Intelligence [5] describe the likely factors that influenced the increase of imaging was due to growing and/or aging populations, an escalation in cancer diagnosis and chronic illness, screening programs, and extended working hours. For CT cranial imaging, the growth of imaging has also risen due to endorsement by the National Institute for Health and Care Excellence [6, 7] as the first-line imaging of choice [8] because of the routine availability of CT that is fast and non-invasive.

The National Institute for Health and Care Excellence guidelines recommend traumatic CT head scans to be reported within one hour [6], and stroke CT examinations to be scanned and reported within one hour [7, 9]. The Royal College of Radiologists (RCR) [10] recommend a formal report for all diagnostic examinations within a maximum of 2 days, but acknowledge due to workforce shortages, this does not occur [4]. With the current number of registered radiologists in the United Kingdom at 2,997 (4.7 working time equivalent consultant radiologists per 100,000 population) [4] this restriction has led to delays in cancer and serious illness diagnosis, prolonged hospital stays, and the subsequent increased registration of radiology departments to NHS risk registers [10].

In October 2014, the RCR [10] highlighted a month delay in results in 25% of English NHS trusts. Follow-up evidence in February 2015 indicated 71% of NHS trusts had delays of over a month for reporting, revealing over 2,883 unreported CT scans, estimated for all English NHS trusts to be up to 3,693 [10]. By May 2016, the RCR stated [11] the backlog had escalated to 263,318 test results being delayed by more than a month (including 4,408 CT reports), affecting 75% of English NHS Trusts. One current response to the crisis that the NHS is attempting is a short term and costly resolution through outsourcing of reporting to private companies at a cost of £73.8 million (2014–2015) [11].

A more efficient and long-term approach would be a larger investment in a skills mix of reporting as promoted and endorsed jointly by the RCR and the Society and College of Radiographers (SCoR) [12–15]. Examples of such an approach have been demonstrated through surveys by the SCoR [16, 17] and Snaith et al [18] illustrating a minimum of 179 radiology departments in the United Kingdom adopting and supporting advanced practice reporting radiographers. The intention of the skills mix of reporting is to supplement current service provision [16], reduce backlogs and improve reporting of acute conditions and early detection of malignant pathologies [19–21]. This advanced practice includes CT head reporting, which has been appraised since 1997 [22], and evidenced in NHS practice since 2007 [15, 23–27].

The aim of this study was to progress the work of previous articles [25, 26] through auditing the reporting performance of the latest cohort of radiographers ($n = 6$) completing a postgraduate clinical reporting course in CT head examinations. The Postgraduate Certificate (PgC) Clinical Reporting (CT Head) program is validated by the SCoR. The course involves part-time, distance learning over one year, which includes academic teaching (by lecturers, consultant radiographers, and reporting radiographers) and clinical department tutorials by mentors. Participants come from all over England to train, since the university is one of only two locations currently providing this specialized and unique course.

Method

Ethics and governance approval for this study were agreed by the Faculty of Health and Wellbeing Research Ethics Committee, with adherence to RCR [28] and General Medical Council [29] best practice guidelines.

An element of the student's proficiency in the PgC program (May 2015–April 2016) involved retrospectively reporting multiple banks of CT head examinations under controlled examination conditions [30] using low-level lighting and high-definition reporting monitors [31] that meet the current RCR reporting specification standards [32] (42 cm, 1280 × 1084 screen resolution, >170 cd/m^2 luminance, $\geq 250{:}1$ luminance contrast ratio). The case studies were displayed in Digital Imaging and Communications in Medicine format using KPACS software [33] to enable manipulation [32].

A retrospectively amassed and anonymized Digital Imaging and Communications in Medicine collection of CT head examinations with referral details (patient gender, age, clinical symptoms, and history) and clinical reports from previous research [25, 26] was used. Each test bank of CT cases had been reported independently by three-experienced consultant radiologists (and blinded to each other's reports, to reduce verification and work-up bias [34]). Expected responses (compiled from the reports of three consultant radiologists [35]) for all of the examinations were then agreed and approved by the program panel and external examiner (independent consultant radiologist), to verify that a suitable and robust range of examples were incorporated. A wide range of pathologic examples was featured to adequately evaluate the students' knowledge and demonstration of competence. The test banks incorporated normal cases up to 50% (variation occurred in each test bank summarized in Tables 1 and 2) and a wide range of subtle and characteristic abnormal (single and multisite) pathologic examples (disease prevalence ranged from 50% to 100% over the test banks are summarized in Tables 1 and 2). Pathologic cases included: hematomas, hemorrhages, cranial fractures, ischemic infarctions, primary and secondary malignant and benign

Table 1
Disease Prevalence Across Clinical Workload Test Banks

Test Bank	Number of Cases (*n*)	RR1, % (*n*)	RR2, % (*n*)	RR3, % (*n*)	RR4, % (*n*)	RR5, % (*n*)	RR6, % (*n*)	Mean Disease Prevalence (%)
Clinical workload mixed test bank 1	125 Minimum	59.3 (128)	38.4 (125)	32 (125)	66.9 (125)	22.4 (125)	34.1 (125)	42.1
Clinical workload mixed test bank 2	250 Minimum	49.4 (263)	50 (250)	44.2 (253)	60.6 (250)	31.6 (251)	38.3 (250)	45.6

cerebral lesions, postsurgical interventions, degenerative changes, and normal variants (to reduce spectrum bias [34]).

The radiographers (RR1-6) were provided with demographic details, including gender, age (18-92 years), referral source (inpatient, outpatient, General Practitioner (GP), Accident and Emergency (A&E), and clinical history for each case. The participants were instructed to comment if they deemed the examination to be normal or abnormal and provide a detailed report of findings (describing the exact anatomic location) to justify and support the diagnosis in the form of a free-text response, including any secondary effects of the primary condition, such as the mass effect on surrounding structures and sulci, herniation of anatomy (and direction of herniation), and if a lesion was identified, the size (in mm) and lesion outline (smooth, nodular, ring, irregular, and contrast-enhancing characteristics). The statistical analysis of the results and marking of the academic banks were completed by two qualified reporting radiographers who run the program, and these were moderated and reviewed by the external examiner (Consultant Radiologist) for validity and reliability as external scrutiny for the examination board.

A recent article by Hardy et al [36] discussed the issue and influence of prevalence bias of pathology on standard academic test bank construction and the resulting accuracy of results. Hardy et al [36] advocated test bank designs to move away from previously established academic models [25, 26, 37] to representative local clinical workloads to reduce bias of high abnormality prevalence that may potentially overestimate observer's competency in abnormality detection. The PgC program used a second tier of observer performance measures of a local clinical workload bank to reflect lower reported incidence of abnormal cases, using prospective clinical worklists in CT (to reduce population bias [34]) from a variety of referral sources, including inpatient, outpatient, GP and A&E, (age range, 17–98 years). Total sample size of cases used was important to reduce the risk of type II error (performance may not be statistically significant but clinically important [38, 39]). Each radiographer (RR1-6) was required to report a minimum of 375 prospective reports at the local NHS Trust from the daily CT worklist as a course requirement. The disease prevalence ranged between 22.4% and 66.9%, as summarized in Table 1. These reports were blind reported by a consultant radiologist for the reference standard and further reviewed and arbitrated by a consultant radiologist, as well as a qualified and experienced CT head reporting radiographer for concordance (to the reference standard [34, 35]). Furthermore, each candidate's prospective bank results were reviewed and moderated by a clinical consultant radiologist (examination board external scrutiny), with statistical analysis by an independent consultant radiologist and two experienced reporting radiographers. The daily worklists used General Electric (GE) Centricity RIS-i 5.0; the scans were produced on the five CT scanners in the NHS Trust (a mix of GE 64 slice CT and Siemens Definition Flash 128 slice CT). The reports were completed in open plan reporting rooms, using EIZO RadiForce RX340 54 cm 3MP (1,000 cd/m^2 luminance, 1400:1 luminance contrast ratio) LCD workstation monitors, running GE Centricity Picture archiving and communication systems (PACS) Radiology RA1000 Workstation and Exam Manager PACS software to review the examinations.

Responses were classified (using a 2×2 contingency table [40]) as true positive, true negative, false positive (FP), or false negative, using fractions (whole and partial) as described in a previous study [25]. Sensitivity, specificity, and accuracy were calculated using standard measures of observer performance [25, 40]; mean values were further analyzed using Cohen's Kappa statistic for interobserver variability [30, 34]. One-way analysis of variance from summary data and Tukey post-hoc test was used for multiple comparisons and significance testing between the observers and against the test bank reference standard at 95% confidence intervals (95% CI).

Results

All radiographers (RR1-6) completed the retrospective academic test banks and achieved the minimum number of the prospective test reports from the local clinical worklists. The primary outcome measures calculated participant mean accuracy (90.7%, 88.3%–93.0%), sensitivity (86.9%, 85.8%–88.2%), and specificity levels (94%, 89.6%–98.3%) summarized in Table 3. No interobserver statistical significance was noted ($P = 0.000$) in the results. The interobserver analysis of variance and Tukey multiple comparison tests were also conducted and summarized in Table 3. The Kappa values for radiographer performance (Tables 2 and 3) across all test banks combined ($k = 0.8114$) and for individual test banks, displayed a high Kappa score of agreement [41] (Table 4).

Discussion

Errors of false negative in the case banks included major discrepancies of midline shift and herniation, linear cranial fractures, subtle subdural hematomas, and small acute

Table 2
Comparison of Mean Observer Outcomes by Test Bank

Type of Bank	Test Bank	Disease	Amount of Cases	Accuracy			Sensitivity			Specificity			Cohen's Kappa		Cohen's Kappa	
		Prevalence		Mean	95% CI	SD	Mean	95% CI	SD	Mean	95% CI	SD	Unweighted	95% CI	Linear Weighted	95% CI
(1) Manufactured test bank	Normal case bank	0%	5	100	100–100	0	0	0	0	100	100–100	0	n/a	n/a	n/a	n/a
(2) Manufactured test bank	Trauma case bank	100%	7	96.4	94.0–98.7	2.27	96.4	94.0–98.7	2.27	0	0	0	0	0–1	0	0
(3) Manufactured test bank	Degenerative case bank	70%	10	65.8	54.9–76.6	10.3	67.8	44.5–91.0	22.12	61.0	20.1–100	38.96	0.2626	0.0036–0.5216	0.2626	0.0181–0.5071
(4) Manufactured test bank	Stroke case bank	100%	13	90.0	83.5–96.4	6.13	90.0	83.5–96.4	6.13	0	0	0	0	0–0.6681	0	1–1
(5) Manufactured test bank	Tumor case bank	100%	8	91.1	86.7–95.4	4.17	91.1	86.7–95.4	4.17	0	0	0	0	0–0.9077	0	0–0
(6) Manufactured test bank	Mixed case bank 1	63%	16	82.2	72.5–91.8	9.15	82.1	71.4–92.7	10.1	83.3	67.6–98.9	14.93	0.6291	0.4692–0.789	0.6291	0.4707–0.7875
(7) Manufactured test bank	Mixed case bank 2	50%	24	95.4	87.4–100	7.6	95.6	87.6–100	7.59	95.2	86.5–100	8.19	0.8957	0.823–0.9684	0.8957	0.823–0.9684
(8) Manufactured test bank	Mixed case bank 3	50%	40	93.1	91.0–95.1	1.94	91.2	89.5–92.8	1.56	95.0	90.3–99.6	4.47	0.8625	0.7985–0.9265	0.8625	0.7985–0.9265
(1) Clinical workload test bank	Mixed case bank 1	42% (22.4%–66.9%)	Min. 125	87.7	84.9–90.4	2.64	75.9	68.1–83.6	7.41	94.0	89.0–98.9	4.76	0.7439	0.695–0.7928	0.7439	0.6954–0.7924
(2) Clinical workload test bank	Mixed case bank 2	45% (31.6%–60.9%)	Min. 250	92.8	89.4–96.1	3.21	89.8	86.9–92.6	2.71	94.8	90.2–99.3	4.33	0.8549	0.8286–0.8812	0.8549	0.8287–0.8811

infarctions in the cerebellum. Minor discrepancies included small chronic ischemia and lacunar infarctions, scalp hematomas, white matter changes, previous mastoid surgery, and included undercalling small associated linear fractures in major trauma cases.

A study by Abujudeh et al [42] on FPs, although using CT abdomen and pelvis examples, reflected the complexity of interpreting multiple pathologies in cross-sectional imaging (with volumetric data reconstruction in multiple planes), establishing major discrepancy rates of 25%–32%. These perceptual errors in failure to detect disease occurred when multiple lesions were present and combined with a failure of "satisfaction of search" patterns [42–47]. Pinto et al [48], Stephens et al [49], and Lee et al [50] estimate errors of searching can approximate to 30%–43% and, although the reasons are multi-faceted, the main factors are misinterpretations. Indeed, it may be difficult to underpin the average error rate in CT reporting, and it may even be underestimated nationally.

The most common FP errors in this study comprised major discrepancies of subtle hemorrhage, middle cerebral artery thrombus, lacunar infarction, and small vessel disease. Minor discrepancies of cerebral calcification, ventricular dilation, and involutional changes were also recorded. Overcalling of FPs also frequently occurred in elderly patients, which included white matter changes. Differentiation between normal and pathologic has been regarded to affect sensitivity rates in previous studies [25, 26]. Consequently, it could be argued that interpretation of the test banks in the academic environment may influence decision-making [51]. With the low level of risk associated in this context, some may have been over cautious with the diagnosis of pathological conditions.

There has been a paucity of evidence on interobserver radiographer performance of CT head examinations to compare against from the current literature [22, 25, 26]. Using academic image test banks in this study allows results to be comparable to previous radiographer's results [25, 26]. Data for interobserver accuracy from clinical workload test banks allowed a predicative value of radiographer's abilities to perform in a clinical environment, where no exact comparable study is available. Using random, but representative, case studies that conform to routine practice allows judgment of competency in clinical practice [40, 52, 53] with strong results (87.7%; cases $n = 753$ and 92.8%; cases $n = 1517$, Table 2). Research by Le et al [54] using a sample size of 10 radiologists and 5 first year fellows reviewing $n = 3{,}886$ cases from an emergency department referral source displayed a similar accuracy rate (97.3%), with discordance of 2.7%. Further research by Erly et al [55] of an equal sample size (15 radiologists) and smaller case bank sample of $n = 716$ (despite a significantly lower disease prevalence of 6.5%, using an emergency only referral source), demonstrated an equivalent range of measures of agreement (95%). Other studies have shown comparable results, including Schriger et al [56] using a larger sample size of 36 radiologists reviewing a smaller sample bank of $n =$ 56 CT scans (75% disease prevalence of stroke referrals) that established a lower accuracy of 83%. Likewise, a smaller study

Table 3
Standardized Performance Results Across All Test Banks

Radiographers	Number of Cases	Accuracy			Sensitivity			Specificity			Cohen's Kappa		Cohen's Kappa		ANOVA	Tukey HSD
		Mean	95% CI	SD	Mean	95% CI	SD	Mean	95% CI	SD	Unweighted	95% CI	Linear Weighted	95% CI	P value (two-tailed)	P value (Post-hoc 95% CI)
RR1	514	86.8	83.5–89.7	10.68	87.5	84.5–90.1	28.94	86.0	82.2–89.2	45.55	0.7346	0.6756–0.7936	0.7346	0.6756–0.7936		RR1vRR4 0.0006
RR2	498	92.2	89.4–94.1	16.74	88.9	86.1–90.8	31.9	95.6	92.8–97.5	44.31	0.8444	0.7974–0.8914	0.8444	0.7975–0.8913		RR2vRR3 0.7848, RR2vRR4 0.0024, RR2vRR5 0.9793, RR2vRR6 0.9999
RR3	501	91.3	88.5–93.2	9.75	85.7	82.6–87.8	29.64	96.0	93.5–97.8	46.26	0.8237	0.7736–0.8738	0.8237	0.7738–0.8736		RR3vRR4 0.1374, RR3vRR5 0.3285, RR3vRR6 0.6992
RR4	498	89.6	86.6–91.7	8.12	87.5	85.1–89.2	28.71	93.1	89.1–95.9	45.75	0.7831	0.7272–0.839	0.7831	0.7276–0.8386		RR4vRR5 0.0001, RR4vRR6 0.0013
RR5	499	92.7	90.1–94.7	7.57	86.4	82.8–89.0	29.64	96.5	94.3–98.0	47.8	0.8427	0.7932–0.8922	0.8427	0.7933–0.8921		RR5vRR6 0.9925
RR6	498	92.3	89.6–93.9	10.26	85.8	82.8–87.7	30.99	97.2	94.8–98.6	46.96	0.8403	0.7919–0.8887	0.8403	0.7921–0.8885		
$n = 6$	3008	90.7	88.3–93.0	10.5	86.9	85.8–88.2	29.97	94.0	89.6–98.3	46.1	0.8114	0.765–0.858	0.8114	0.7599–0.8629	0.0000	

ANOVA, analysis of variance; HSD, honest significant difference.

Table 4
Value of Cohen's Kappa Strength of Agreement [41]

Kappa Score	Agreement Strength
<0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

by McCarron et al [57] reviewed 9 radiologists reading $n = 77$ CT head examinations, and obtained an agreement of 86.6%.

The method used evidences current best practice policy in training to expose participants to both academic retrospective example test banks and clinical prospective workload banks of images, to present a varying mix of normal or abnormal cases to reduce prevalence bias on interpretation. High-prevalence case banks used in training have been shown to nurture a desirable sensitivity–specificity compromise [58, 59] in cases where abnormalities have major health implications. Likewise, "context bias" [60] has been shown to influence the interpretation and evaluation of varying prevalence (preset high and low abnormality) test banks, which illustrates the complexity in achieving unbiased performance levels; although this is not without its critics and challenges to provide exact measures of accuracy in performance using varying levels of disease prevalence [50, 61, 62].

Defining a satisfactory level of performance for CT head reporting by radiographers is a difficult task, and is often dependent on adequate sample size determination and statistical power. Scally and Brealey [39] use an expected example of 80% sensitivity and 95% specificity (60% disease from 250 to 335 cases, using 95% CI), but note these figures will alter with varying prevalence of disease and case number in test banks.

Furthermore, it would be useful for future research to re-evaluate these results through clinical audit after qualification, following best practice frameworks by the SCoR [14] and RCR [63] quality improvement guidelines, to maintain a record of measure of performance. This practice is important in rapidly developing modalities where the volume of data per patient is increasing per examination, raising the complexity of reporting, which can be a factor contributing to misinterpretation errors of clinically important findings in discordant CT examinations [64, 65].

Conclusions

The radiographer's performance demonstrated similar results to previous research [25, 26] on observer performance and competency. The discrimination parameter of using a prospective random clinical workload model for testing radiographer's interpretative findings provided similar results to the academic retrospective test results, and the differences did not provide statistically different results.

The data suggest appropriately trained radiographers can successfully undertake reporting of CT head examinations to a high standard. A recognition of the limitations when comparing results between the academic test banks ($n = 738$ cases) and the local clinical workload test banks ($n = 2270$ cases) needs to consider the difference of sample size that can influence results, although this was not an aim of this audit. The adoption of both academic and clinical test banks that reflect disease examples and the prevalence that may logically be encountered in practice offers the potential for an accurate measure of performance of radiographer's abilities. Recommendations from this study include further research to review the postqualified clinical audits of reports for quality, consistency, and concordance.

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AFROC analysis of reporting radiographer's performance in CT head interpretation

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ABSTRACT

Aim: A preliminary small scale study to assess the diagnostic performance of a limited group of reporting radiographers and consultant radiologists in clinical practice undertaking computed tomography (CT) head interpretation.

Method: A multiple reader multiple case (MRMC) alternative free response receiver operating characteristic (AFROC) methodology was applied. Utilising an image bank of 30 CT head examinations, with a 1:1 ratio of normal to abnormal cases. A reference standard was established by double reporting the original reports using two additional independent consultant radiologists with arbitration of discordance by the researcher. Twelve observers from six southern National Health Service (NHS) trusts were invited to participate. The results were compared for accuracy, agreement, sensitivity, specificity. Data analysis used AFROC and area under the curve (AUC) with standard error.

Results: The reporting radiographers results demonstrated a mean sensitivity rate of 88.7% (95% CI 82.3–95.1%), specificity 95.6% (96% CI 90.1–100%) and accuracy of 92.2% (95% CI 89.3–95%). The consultant radiologists mean sensitivity rate was 83.35% (95% CI 80–86.7%), specificity 90% (95% CI 86.7–93.3%) and accuracy of 86.65% (95% CI 83.3–90%). Observer performance between the two groups was compared with AFROC, AUC, and standard error analysis ($p = 0.94$, SE 0.202).

Conclusion: The findings of this research indicate that within a limited study, a small group of reporting radiographers demonstrated high levels of diagnostic accuracy in the interpretation of CT head examinations that was equivalent to a small selection of consultant radiologists.

Introduction

The number of head injured patients attending district general hospitals has been estimated by the United Kingdom (UK) Acquired Brain Injury Forum[1] during 2011–2012 to be around 353,059 UK patients. These figures estimate around 558 per 100,000 of the population experience head injuries each year. This represents a 33.5% increase in the last ten years (10,000–20,000 per year in the UK) of admissions for severe traumatic brain injuries.

Both the National Health Service (NHS) and the Department of Health (DoH)[2–6] have a strong ethos of developing and improving patient outcomes and service delivery. With the NHS currently undertaking the ‘Nicholson Challenge’ (2006–2015)[7] to generate extra productivity and service quality improvement, set by Sir David Nicholson. Within radiology additional NHS drivers for change include pressures from DoH targets of the acute 4 h waiting time,[8] cancer ‘referral to treatment’ 18 week target waits,[6] and the National Diagnostics Imaging Board[9] policies on reporting targets. Specifically within computed tomography (CT) as a modality, National Institute for Health and Clinical Excellence (NICE) guidelines[10,11] of reporting turnaround timeframes for stroke and head injury examinations have changed historic working practices with the need for urgent 30 min to 1 h verbal and written CT head reports. This coupled with an increase in the amount of CT examinations that have increased by 33.5% a year since 2008[12] have emphasised the need to re-evaluate how the service delivery can accommodate future pressure.

Barriers to improving current working practices include staff shortages (radiographers and radiologists) to implement new guidelines, and the current dilemma of implementing a full 7 day

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service delivery with restricted service capacity. Within diagnostic imaging, the Royal College of Radiologists (RCR) Clinical Radiology Workforce Report[12] recommended a level of 47 consultant radiologists per million of the population for the UK. The reported RCR[12] level for the south of England was 30 per million, the lowest of all regional variations. With a deficit of 210 unfilled NHS consultant radiologist posts in the UK, the RCR[12] report advised that the current consultant radiologist workforce does not meet the required needs of the radiology service demand. The report indicated 85% of UK radiology departments reporting workload was not being adequately completed by the consultant radiologist workforce. The RCR[12] estimated the shortfall in reporting to be 47% of all examinations were left unreported in 2011, the report discussed action to address the shortfall including “radiographers can now make a contribution to the reporting workload”.[12]

In identifying potential ways to reduce reporting delays and increase service provision, a skills mix of reporting has been promoted and endorsed jointly by the RCR and the Society and College of Radiographers (SCoR).[3,13,14] Examples of such an approach have been demonstrated in surveys by the SCoR[15,16] which showed at least 17 NHS trusts in the UK had adopted and supported role extension of reporting radiographers to supplement their service provision by 2012.[15] This has helped to improve service delivery of reporting traumatic injuries and assisted in the early detection of pathological conditions and cancers.[2,4,5]

Aims and objectives

The study hypothesis predicted reporting radiographers would have a diagnostic accuracy comparable or equal to consultant radiologists in CT head interpretation in a clinical setting. To answer the hypothesis, the research study set inter and intra-participant objectives within the study: Identifying statistical interpretation results for variation or equivalence rates between two groups of participants (consultant radiologists and reporting radiographers) undertaking the same image bank analysis.

Methodology

The design followed a multiple reader multiple case (MRMC) retrospective study of CT head interpretation by reporting radiographers ($n = 6/6$) and consultant radiologists ($n = 2/6$) at 6 NHS hospitals within the southern region of the UK.

Chang[17] suggests that any experimental study which evaluates the efficiency of reporting standards by Bayesian analysis must use an explicitly defined reference standard. The study adopted a retrospective method using patient cases with known true disease status from a collection of 125 cases previously obtained by the University for teaching and research. This had been additionally double reported by two independent consultant radiologists. Brealey[18] and Robinson[19] advise that employing a triple approach to obtaining a retrospective reference standard enforces validity of the reference standard.

Brealey[18] discusses issues of internal validity of research as the amount and range of presenting conditions used in the control group (image case bank). This included a selection of malignant and benign cerebral tumours, vascular disease (including ischaemic infarction), traumatic haemorrhage and haematomas, with associated bone fractures, mass effect and midline shift. The cases used reflected a suitable range of subtle and textbook examples to determine high levels of accuracy to remove internal validity concerns. Displaying a fair representation of pathologies as recommended by Robinson et al.[19] and Brealey,[18] and similar to methods used in comparable research.[20–24] Concerning the frequency of cases with and without disease in the test bank, Brealey[18]; Metz[25]; Brealey and Scally[26]; Thompson et al.[27]; and Piper, Paterson and Ryan[28] endorsed a balanced approach to the ratio of normal to abnormal conditions (1:1).

The test bank was reviewed within the participant's clinical departments under ambient lighting settings for radiological reporting environments. The images were displayed on a Toshiba Windows Notebook Laptop with a Liquid Crystal Display (LCD) monitor with resolution of 1280 × 1024. The laptop had been calibrated to the Digital Imaging and Communications in Medicine (DICOM) part 14 Greyscale Standard Display Function (GSDF) with the VeriLUM software programme.[29] Quality checks were performed on the Laptop LCD monitor prior to each test with a standard diagnostic imaging Society of Motion Picture and Television Engineers (SMPTE) reference pattern for spatial uniformity of luminance and temporal luminance stability as recommended by the RCR.[30] An independent PACS system of iQ-View software programme[31] was used to display the cases in a sequential order.

The recruitment criteria of participants required completion of SCoR accredited training and qualification in CT Head reporting, with completion of a period of post training experience of independent reporting within an NHS hospital trust (ranging from 1 to 10 years). Obuchowski[32] proposes designs of an MRMC Phase 1 pilot study only requires a small selection of 10–50 cases, of which we choose 30 cases from the bank of 125 cases to be double reported. Obuchowski[32,33] also suggests in MRMC studies of difficult cases in terms of disease prevalence and appearances should include between 5 and 10 observers to compare groups of observer's performance.

Six reporting radiographers were invited to participate ($n = 6/6$ completed the study), and six consultant radiologists were invited to participate in the study ($n = 2/6$ completed the study). Each participant was provided with a copy of instructions detailing the patient history, presenting symptoms, age, gender and referral source, for each case. The participants received these instructions in person by the researcher and were collected after each participant session for compiling of the raw data.

The study required participants to record their findings as either normal or abnormal. If the case was normal they marked the case 0, and moved on to the next case. If the participant deemed the case to be abnormal, they recorded a score of 1–4 (very low to very high confidence of an abnormality) and recorded the name of the pathological condition seen, the anatomical location of the condition/disease and their confidence score of the interpreted pathology. The confidence classification score and free response text allowed the results to be analysed by true positive (TP), true negative (TN), false positive (FP), and false negative (FN). Allowing calculations of accuracy, agreement, sensitivity and specificity using a method adopted by Piper, Ryan and Paterson[28] and Piper, Buscall and Thomas.[34]

In MRMC studies the use of the AFROC method is ideal when the amount of abnormalities and locations are required to be identified, and ranked each against values according to the confidence levels. Particular attention to the location of the lesion identified to within an acceptance radius (proximity criterion emanating for the centre of the suspected lesion-location (LL) Thompson et al.[35]) allowed the researcher to class the participant's responses as LL (true location of abnormality = TP) or non-lesion (NL) location (wrong location of abnormality = FP or FN).

Chakraborty[38] cautions that the conventional receiver operating characteristic (ROC) paradigm does not distinguish statistical differences for incorrect location (FP), if multiple lesions are present the ROC would classify a TP result even if all the abnormalities were not identified or anatomical location described correctly. Significant clinical implications which may impact on treatment cannot be accounted for in this scenario. Chakraborty[38] advocates AFROC curves over conventional ROC curves, as they provide an increased power due to lesion localisation.

Jackknife free-response ROC (AJFROC) calculations were considered for the data analysis but were rejected on the grounds that the output and statistical tests assume paired analysis of two modalities not readers. The use of single modalities violates the assumption of the calculations. Additionally a test run produced a zero score for the incorrect localisation fraction (ILF), thus it had in this instance no power advantage over AFROC analysis.

Conventional ROC plotting generates a curve using the axis of true positive fraction (TPF) in this case sensitivity, versus false positive fraction (FPF) which is calculated as 1-specificity (Thompson et al.[35]). AFROC plotting uses a mixture of conventional ROC methodology and free response ROC (FROC) calculations. FROC is a variant of ROC which was designed to reduce the ROC limitations of a binary yes/no answer and instead determine scoring of multiple lesions per case with unlimited location identification (Thompson et al.[35]). FROC calculations replace the FPF with non-lesion fractions (NLF) on the x-axis, and number of lesions (lesion location fraction (LLF)) on the y-axis. AFROC is a combination of both paradigms and uses LLF on the y-axis (the same as FROC) and FPF on the x-axis (the same as conventional ROC calculations) Thompson et al.[35]

The study was approved by the university research ethics and governance committee and conformed to Section 33 of the UK Data Protection.[37] The radiology source data (identifying narrative elements including staff names, hospital name, and identifying patient data) had been manually removed to anonymise the images. This practice follows Cosson and Willis[38] guidance from the National Information Governance Board for Health and Social Care, and the General Medicine Council.[39]

Results

The results for the reporting radiographers ($n = 6$, Ranked RR1-RR6) from six NHS hospitals judged against the reference standard are shown in Table 1. The conjectured accuracy predictor by Obuchowski[36] for intra-observer variability listed high accuracy to be 90% (specificity/sensitivity 80%). For the reporting radiographers, 4 out 6 scored higher than 90% in accuracy (the lowest score was 88.3%, mean 92.2%), for sensitivity 5 out of 6 scored over 80% (lowest score 78%, mean 88.7%), and for specificity all scored over 80% (lowest score 86.7%, mean 95.6%). Comparison of the AUC was calculated using MedCalc[40] to obtain individual AFROC plotting (Graph 1 and 2, and Table 2), and a mean AUC value of 0.903 (95% CI 0.835–0.948). MedCalc[40] calculations to produce the AUC used methodology by Metz,[41] Griner et al.[42] and Zweig and Campbell[43] which advised would give increased power and sensitivity to the results from this method than from using traditional t-test comparison calculations.

Further calculations using MedCalc[40] which applied DeLong, DeLong and Clarke-Pearson,[44] Hanley and Haijian-Tilaki[45] and Hanley and McNeil[46,47] sampling comparison methodology produced a reporting radiographer mean standard error (SE) analysis of 0.020033.

Table 1
Reporting radiographers results compared to the study reference standard.

Participant	Sensitivity	Specificity	Accuracy	FP	FN	TP	TN
RR1	96.6	91.8	94.1	1.25	1.25	14.25	14
RR2	88.1	98.4	93.3	0.25	1.75	13	15
RR3	78	98.4	88.3	0.25	3.25	11.5	15
RR4	91.7	86.7	89.2	2	1.25	13.75	13
RR5	90	100	95	0	1.5	13.5	15
RR6	88.1	98.4	93.3	0.25	1.75	13	15
Mean	88.75	95.61	92.2	0.66	1.79	13.66	14.5

The results for the consultant radiologists ($n = 2$, Ranked CR1-CR2) judged against the reference standard are shown in Tables 3 and 4. The consultant radiologists for sensitivity scored 80% and 86.7% respectively, for specificity all scored over 80% (86.7%, and 93.3%), accuracy was judged to be 83.3% and 90%. Comparison of the AUC was calculated using MedCalc[40] to obtain individual AFROC plotting (Graphs 3 and 4, and Tables 3 and 4), and a mean AUC value of 0.888 (95% CI 0.817–0.936) and an SE of 0.026. A test of the comparison between the RR and CR AUC and SE, resulted in $p = 0.9408$ and SE 0.202, inferring that the AUC was not statistically different between the cohorts.

Discussion

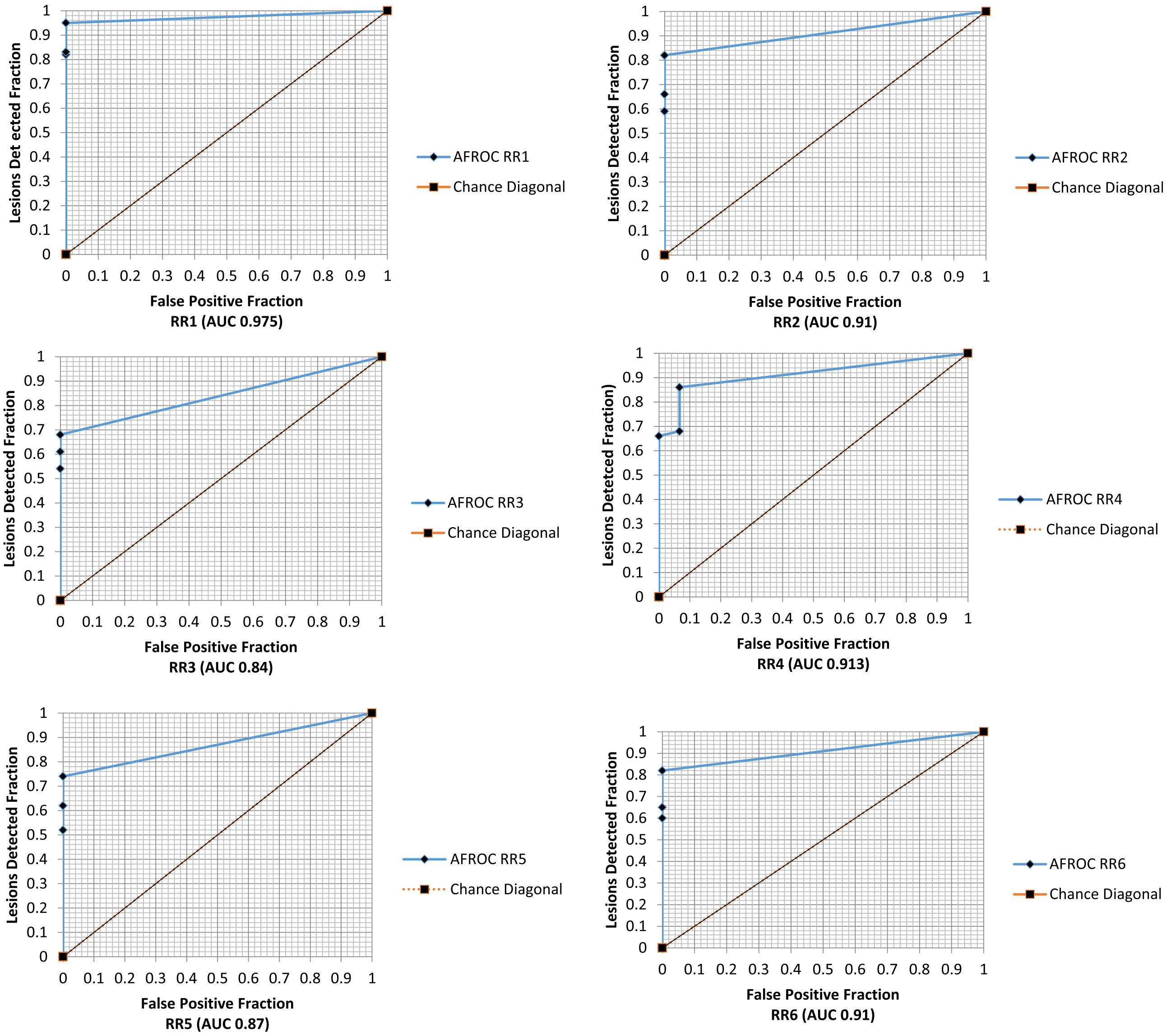
A common issue with conventional ROC scoring of participants raw data is the potential for degenerative data. Metz[25] discussed controversies of converting raw data into ROC curve plotting; where the data scale is too discrete to produce ROC curves and AUC calculations. In response to this Metz[25] advised to use AFROC plotting to obtain AUC scores for valid statistical significance in MRMC studies of reader variation. In this study the participant's case bank of 30 CT head examples contained a possible 115 scores of LL or NL with associated location and confidence scores to give an accurate description of the participant's diagnostic threshold.

Obuchowski[32] and Chakraborty[36] recommend ROC curves and AUC as a global measure of accuracy and performance. In pathology interpretation where false negative scores could have significant complications, a high sensitivity (TP rate) and specificity (TN rate) is recommended. Obuchowski[33] advises the use of sensitivity at an FP score equal to or less than 0.10 (specificity > 0.90). This high level of sensitivity and specificity in ROC studies has been set to a standard that reflects the seriousness of the interpretation of pathology on patient outcomes and treatments (avoidance of surgery or other diagnostic tests, hospital stay, or abandonment of clinical treatment). Fineburg et al.,[48] Fryback and Thornbury[49] and Brealey[18] emphasise the interpretation of imaging in the chain of clinical efficacy must set high standards to reduce the risk of error and harmful patient outcomes.

Six electronic databases (Cochrane, Medline, Europe Pubmed Central, CINAHL, ScienceDirect and Google Scholar) were searched to find comparative CT head interpretation studies. The literature search located 45 papers; only one non-peer review journal paper displayed the results of a reporting radiographer's CT head interpretation study.[50] The paper did not provide sufficient details as to the methodology, data, sample size or statistical analysis used, although the limited results displayed a high sensitivity and specificity.

The review of literature evaluating consultant radiologist's interpretation of CT head scans allowed analysis of the summary estimates to calculate a broad estimation of the combined results. The most statistically detailed study found was Erly et al.[51] who studied 15 consultant radiologists reviewing 716 CT head scans (649 were normal). The results produced an agreement level of 95%, sensitivity 85.7%, specificity 99.7% and accuracy of 99.4%.

Further published studies found limited statistical details on diagnostic thresholds for consultant radiologist's interpretation CT head examinations. Nagaraja et al.,[52] studied 6 consultant radiologists reviewing 270 paediatric CT head examinations of subtle fractures and congenital abnormalities, found 84.1% agreement and 15.9% disagreement. Le et al.[53] on the findings of 10 consultant radiologists reviewing 1736 cases of which 48 were reported as discordant, gave a concordance rate of 97.2%. A similar study by



RR1 (AUC 0.975)

RR2 (AUC 0.91)

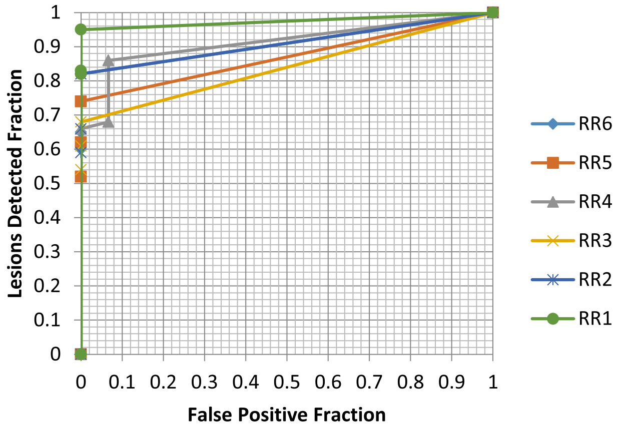
RR3 (AUC 0.84)

RR4 (AUC 0.913)

RR5 (AUC 0.87)

RR6 (AUC 0.91)

Graph 1. Reporting radiographer AFROC and AUC results.



Graph 2. Comparison of reporting radiographer AFROC results.

Table 2
Reporting radiographer AFROC results.

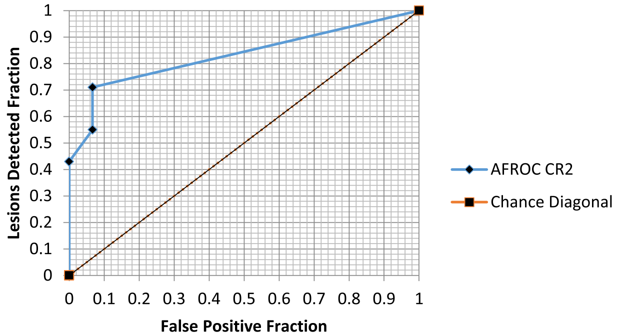
	AUROC	SE	95% CI
RR1	0.975	0.0110	0.927–0.995
RR2	0.910	0.0193	0.842–0.955
RR3	0.840	0.0234	0.760–0.902
RR4	0.913	0.0252	0.845–0.902
RR5	0.870	0.0220	0.795–0.925
RR6	0.910	0.0193	0.842–0.955
Mean	0.975	0.0365	0.835–0.939

Table 3
Consultant radiologist results compared to the study reference standard.

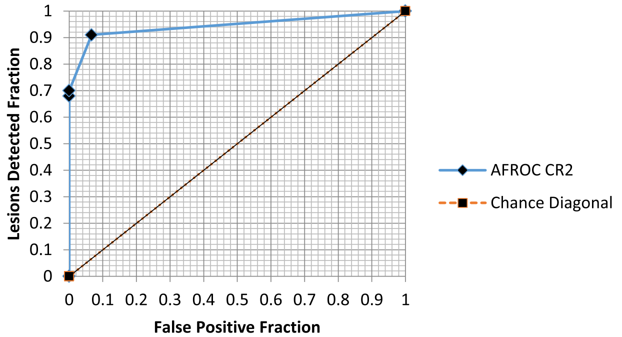
Participant	Sensitivity	Specificity	Accuracy	FP	FN	TP	TN
CR1	80	86.7	83.3	2	3	12	13
CR2	86.7	93.3	90	1	2	13	14
Mean	83.35	90	86.65	1.5	2.5	12.5	13.5

Table 4
Consultant radiologist AFROC results.

	AUROC	SE	95% CI
CR1	0.831	0.0338	0.749–0.864
CR2	0.945	0.0182	0.886–0.979
Mean	0.888	0.026	0.817–0.921



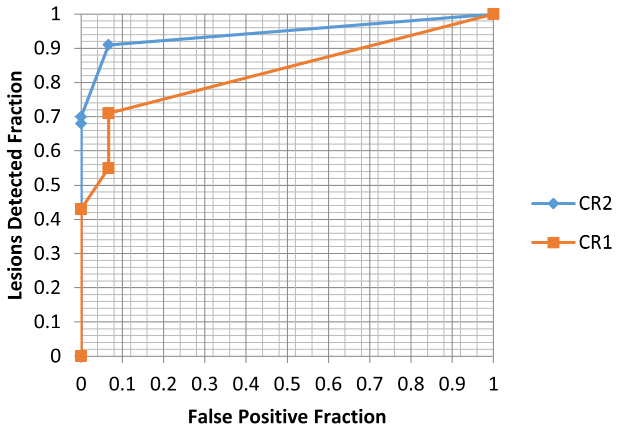
CR1 (AUC 0.831)



CR2 (AUC 0.945)

Graph 3. Consultant radiologist AFROC results.

Briggs et al.[20] produced a 66% agreement and 44% discordance rate. McCarron et al.[21] studied 9 consultant radiologists reviewing 77 CT head examinations, obtained an agreement of 86.6%. Schriger et al.[54] used a multiple site, multiple case methodology of 36 consultant radiologists reviewing 56 CT scans established an accuracy of 83%. A recent neuroradiologist study by Guérin[55] in an academic setting studied interobserver agreement by 8 neuroradiologists to be 86% (95% CI 0.77–0.95) with 75.6% discordance of findings.



Graph 4. Comparison of consultant radiologist AFROC results.

When considering the accuracy of interpretation, Obuchowski[33] suggests high accuracy to be 90% (specificity/sensitivity 80%). The literature search and analysis provided a reasonable estimation of consultant radiologists from the published literature reviewed studies. The averaged estimated consultant radiologist reference standard was 83% accuracy, and 85.5% agreement (95% CI 73.0–97.0%, $p < 0.271$) from results by Schriger et al.[54]; Erly et al.[51]; Le et al.[53]; Briggs et al.[20]; Nagaraja et al.[52] and McCarron et al.[21] The literature showed that the majority of consultant radiologist study results had not supplied sufficient data to accurately calculate a pooled sensitivity or specificity for consultant radiologists. In comparison from the limited small sample of observers which is not generalisable to the greater population, our preliminary study found reporting radiographers mean accuracy to be 92.2%, and from the small sample of consultant radiologists 86.6%, which is above the mean of the published literature.

Conclusion

The aim of this limited scale preliminary research was to achieve an understanding of the degree of image interpretation accuracy of a small sample of CT head reporting radiographers and consultant radiologists in a clinical environment.

The study findings suggested that a small sample of reporting radiographers displayed a high level of accuracy in the interpretation of CT head examinations, which was equivalent to a small sample of consultant radiologists, and were consistent with the published findings of other studies in this field. It is recommended further funded research needs to be undertaken to establish the degree of accuracy of a larger sample of participants.

Funding

There are no financial conflicts of interest.

Conflict of interest statement

The author *a* is a programme leader and author *b* programme director for the postgraduate CT head reporting course at CCCU.

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Corrigendum

Corrigendum to ‘AFROC analysis of reporting radiographer's performance in CT head interpretation’ [Radiography, 21 (2015) e90–e95]

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The authors regret the inclusion of errors in their original paper. The original article should be read in conjunction with the following:

- Page e93, ‘Chance diagonals’ shown on the AFROC plots are normally for use in ROC plots and should have been omitted. [Reference: Chakraborty, D.P. and Winter, L.H. (1990) ‘Free-Response Methodology: Alternative Analysis and a New Observer-Performance Experiment’, Radiology, 174(3 Pt 1), pp.873–881]
- The initial AFROC curve plots were calculated on JAFROC 4.2.1. [Reference: Chakraborty D. JAFROC v4 software (Version 4.2.1); 2014. Available at: http://www.devchakraborty.com/]
- Page e93, the y-axes of the AFROC plots are mislabelled and should read ‘Lesions Location Fraction’. [Reference: Chakraborty, D.P. (2011) ‘New Developments in Observer Performance Methodology in Medical Imaging’, Seminars in Nuclear Medicine, 41, pp.401–418]
- Page e92 paragraph 7, Metz25did not advocate the use of AFROC, but raised validity issues in choosing which of ROC, FROC and AFROC is most appropriate when designing studies of absolute measurement vs ranking studies, and discrete vs continuous confidence rating scales. This has been further discussed by the work of Chakraborty. [Reference: Chakraborty, D.P. and Berbaum, K.S (2004) ‘Observer studies involving detection and localisation: Modelling, analysis and validation. Medical Physics, 31(8), pp.2313–2330]
- Page e91 paragraph 5, the case bank included single and multiple pathologies.
- Page e93 & e94, the use of accuracy levels can be viewed as unwarranted in disease prevalence studies. The confidence classification score and free response text allowed TP, TN, FP and FN fractions to be allocated. This enabled sensitivity and specificity rates to be estimated manually. [reference 17]
- Page e91 paragraph 8, Obuchowski32 discusses studies assessing a new technique, for the purposes of this study we have regarded reporting radiographers as a new technique to interpret CT head scans.
- Page e91 paragraph 11, the abbreviation AFROC is incomplete and should read ‘alternative free-response receiver operating characteristic’.
- Page e91 paragraph 11, the abbreviation NL is incorrectly placed and should read non-lesion localisation (NLL).
- Page e91 paragraph 12, Chakraborty reference should be numbered as 36 not 38.
- Page e92 paragraph 1, the correct term should be ‘jackknife alternative free-response ROC (JAFROC).

The authors would like to thank Prof. D. Chakraborty and Dr. J. Thompson for their helpful comments which have contributed to this corrigendum.

The authors would like to apologise for any inconvenience caused.

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Exploring variation and trends in adherence to national occupational standards for reporting radiographers

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Abstract

Purpose: The primary aim of this study was to observe variations and trends in the implementation and conformity to guidelines and standards in the advanced practice role of radiographer reporting within the United Kingdom (UK) National Health Service (NHS) trusts.

Method: A questionnaire using a 5-point Likert categorical response scale, and free text open questions were applied. The engagement process used an on-line survey, which was sent out between July and August 2015 to NHS reporting radiographers. The inclusion criteria covered a cross section of imaging modalities including plain film, computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine (NM), fluoroscopy, and mammography.

Results: A total of 261 radiographers completed and returned the survey. Commenting on a selection of questions based on four key themes: (1) scope of practice (74.3%; *n*=168/226 responded as having a detailed scope of practice), (2) education and training support (55%; *n*=125/227 had no mentor allocated), (3) resources and equipment (48%; *n*=102/212 did not have access to dedicated equipment); and (4) outcome measures of performance (only 36%; *n*=77/216 regularly audited their workload).

Conclusion: The results of the data collected, identified specific trends in the sample group on defined scope of practice, and the level of organisational support. It was implied from the varied responses on equipment and resources provided to fulfil the role, that best practice guidance on resources should have a clearly defined area in future frameworks and policy to support safe working practices. The diverse responses to the survey suggest adherence to recommended best principles in reporting were not consistent within this sample group. The main trends noted from the survey data centred upon on parity of support, equipment, scheduled sessions, audit mechanisms and cross-cover of service provision.

Introduction

The United Kingdom (UK) National Health Service (NHS) is under considerable pressure to deliver the NHS Five Year Forward[1] whilst developing and employing new models of care based on local Sustainability and Transformation Plans that are responsive to the challenges of the changing healthcare sector and local population demands. However, there is a requirement to maintain standards in healthcare which is paramount to progress the quality of services to patients when establishing new service models and health profession roles.

The Royal College of Radiologists (RCR) review of acute and primary care NHS radiology services[2, 3] proposed that healthcare organisations have a responsibility to provide an adequate quality of service through the establishment of guidelines to maintain standards in practice. In radiography, it is the duty of governing and professional bodies such as the Department of Health,[4-7] and the Society and College of Radiographers (SCoR)[8-9] to develop, appraise and embed these frameworks into clinical practice.

Advanced practice radiographer reporting has been established for over twenty years within the NHS allied health professions, and is just one of many developments in service delivery improvement projects[10] that in recent years have improved patient management and treatment pathways. However, there is evidence in contemporary literature of a wide variation in interpretation and implementation of the role within the NHS.[11-19] The SCoR are currently progressing a voluntary accreditation and registration scheme of advanced practice radiographers,[20] which builds upon the existing Department of Health (DoH)[4] four tier skills mix system, to standardise and regulate the introduction of advanced practice roles.

Research on reporting radiographers' practice has previously focused on factors of inter and intra-observer variability and performance, cost effectiveness and clinical impact.[11-19] The aim of this study was to explore variation and trends in adherence to national occupational standards[8-9, 20-26] for reporting radiographers.

Method

A literature search was undertaken to review previous research and standards of advanced practice using PubMed Central, OVID, CINAHL, ScienceDirect, and professional body documents (SCoR,[8-9, 20-23] RCR,[3, 24-29] DoH,[4-7, 30] Health and Care Professions Council[31-32] (HCPC), and Skills for Health).[33] The SCoR advanced practice frameworks detailed a range of practice duties for reporting radiographers to be considered against, which fit broadly into four areas. These are a defined scope of practice, governance and audit of work, professional registration (code of conduct, ethics, and accountability), and education (training and continuing professional development (CPD). These four pillars of advanced practice are reflected in other national policies and guidance for reporting radiographers that set out the basic threshold standards to adhere to (Appendix 1).

It was deemed that the participants in the survey were already registered with mandatory professional bodies such as the HCPC in order to practice, so assessing this area would provide no meaningful data. This category was replaced with resources and equipment which was a critical area noted in previous research on observer performance in advanced roles.[28-29, 34-36] This prompted an adaption of the four categories into: (1) scope of practice, (2) education and training (organisational support), (3) resources and equipment (working conditions), and (4) measure of performance (governance and audit) as the main questions in the survey.

An online questionnaire using a 5-point Likert scale of ordinal response levels (never, rarely, sometimes, often, all the time) based on the four categories, was employed to obtain data on current practice. The advantage of a web-based survey allowed results to be collected from a wide geographical area, in a short time frame, in a cost-effective and efficient way.

Using a sample size calculator for the target population was problematic, as a current register of reporting radiographers does not exist. Instead, the sampling frame consisted of a population list of qualified postgraduate reporting radiographers (*n*=427) from this higher education institute (HEI) and contacts at reporting special interest groups (SIGs) and consultant radiographer groups provided by the SCoR. An acknowledgement of the sample bias included missing elements (an incomplete register of all practising UK reporting radiographers); foreign elements (reporters trained at other HEI's) and duplicate entries (former students who are associates of SIGs).

Ethics and governance approval were agreed by the Faculty of Health and Wellbeing Research Ethics Committee to contact potential participants. The initial contact included information on the study, consent to participate (with the right to withdraw at any point), confidentiality of response, and information on the dissemination of results. To increase potential responses, the initial contact also asked participants if they would like to contribute to the survey response rate via snowball sampling through their local network of reporting radiographer colleagues and peers.

Steps taken to mitigate potential response bias from contributing an effect on the results included a broad cross-section of responders (no restriction on gender or age, geographical location was centred on UK NHS providers, and multiple imaging modalities) in the sample group (with no control group bias). Strategies to further reduce response bias included neutral, negative and positive format questions for responder consistency, with forced choice questions that require rating scales. The use of self-administration of the questionnaire additionally helped to reduce social desirability bias. The inclusion criteria covered a cross section of imaging modalities, including X-Ray (computed radiography and digital radiography), computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine (NM), fluoroscopy, and mammography. A decision was made not to include ultrasound within the sample frame due to the current UK government position on the title of sonographer not being legally protected. Thus, sonographers are not required to register with a professional body for regulation or have a legal requirement to act in accordance with a national standard or benchmark guidelines, as a radiographer does. This implication makes them exempt from adhering to and comparison against the same advanced practice requirements as reporting radiographers, although it was noted that radiographers could and do hold this title and role.

A pilot questionnaire was tested on a small sample of reporting radiographers (*n*=5) to review the readability, terminology, and accessibility of the electronic survey. Pilot feedback allowed minor revision to include open questions with free text responses to capture additional information from the participants.

The on-line survey was sent out between July and August 2015, to English and Welsh NHS trusts, Scottish Health Boards, and Northern Irish Health and Social Care services. The SCoR provided additional support, information and participation links to the survey on their news website and Synergy journal.[37] The survey was hosted on-line through Qualtrics[38] software, analysis of the Likert scale data to identify specific trends used Excel software[39] for coding of responses, and Social Science Statistics[40] on-line calculator for Chi-Square test for variations in categorical response.

Results

The number of respondents that completed the survey within the given timescale was 261 (61% *n*=261/427). A proportion of the returned surveys did not complete all questions, which was reflected in the sample size of answers. The geographical spread of response data was small with only 18% of participants providing their location as England (12%), Wales (4%), and Scotland (2%), leaving the remainder practising within unspecified hospital locations in the UK. The categories of participant roles came from X-ray (73%), CT (8%), MRI (5%), and mammography (14%), with no returned surveys stating NM or Fluoroscopy practice.

Scope of practice

Concerning the current professional body guidelines and national standards requirement for advanced practice radiographers to work within an agreed and defined scope of practice. The majority of respondents (74%; *n*=168/226; $X^2 = 107.07$; $p < 0.05$) reported having a scheme of work defined within their job description. Which detailed a protocol of examinations covered, referral pathways accepted, with local variations and mode of reporting described. Details of how this was reflected in practice revealed a large majority of radiographers (79%; *n*=174/220) always had scheduled and planned reporting sessions. Impacting factors indicated in the data showed that only 30% (*n*=65/216) of radiographers disclosed that their departments had an adequate staffing capacity to provide a routine reporting service. Further, likely factors demonstrating a potential disruption to fulfil their advanced practice role included a third of respondents (33%; *n*=72/219) stating that they were occasionally taken out of reporting sessions to cover other general radiography, cross-sectional imaging, and screening roles.

The types of reporting sessions described by the respondents were defined into three distinct classifications. Hot reporting (26%; *n*=56/213), cold reporting of backlog examinations (36%; *n*=78/215) and undefined reporting sessions. With half of the radiographers (54%; *n*=116/215) not required to cover for a duty/day radiologist for queries related to reports while reporting. Consideration of interruption to workflow from this activity can be a potential risk to concentration and accuracy of the task. It was noted the majority of participants (75%; *n*=164/218) stated they did not have a set or defined target for the number of reports per session within their scheme of work. Free text responses reflected the variety of reporting output per session/modality that was documented in the responses.

> *"Minimum of 40 reports per 3 hour session for plain film, regardless of referral pathway"*
>
> Respondent 26
>
> *"Approximately 60-70 plain film reports per morning or afternoon session"*
>
> Respondent 58
>
> *"A minimum of 80 cases reported in a 4 hour session"*
>
> Respondent 81

"100 per session, which equates to 3.5 hour session for plain film"

Respondent 103

"50 A&E appendicular reports per 3 hour session"

Respondent 112

"60 examinations (CXR & AXR would count as 1 examination) per session which is 3.75 hrs"

Respondent 119

"I expect to do at the very least, 100 reports in a day, allowing for interruptions, phone calls and queries from A&E"

Respondent 132

"6 CT head reports per 3 hour session"

Respondent 147

"12 Outpatient CT head reports per morning session"

Respondent 168

"20 CT head reports per 7.5 hours session"

Respondent 172

"12 CT colograms per 4 hour session"

Respondent 177

"150 Mammograms per 4 hour session"

Respondent 189

"75 Mammos per 3 hour session"

Respondent 193

"Around 80 chest examinations in a 4 hour reporting session"

Respondent 198

"30 chest reports in a 3 hour session"

Respondent 201

"12 MRI's in a 4 hour session"

Respondent 207

The amount and length of rest breaks were an additional influence in considering the amount of possible reports completed per session. A range of data was recorded on this subject, with some radiographers having between 10-15 minutes per reporting session, to others on an ad-hoc basis. It was also acknowledged a substantial group (45%; *n*=96/213) had no agreed rest periods during their reporting sessions.

> *"There are no agreed breaks, rest breaks are down to the individual, as long as the number of exams are covered per session"*
>
> Respondent 37
>
> *"We have none agreed, but we are allowed to make a drink"*
>
> Respondent 93
>
> *"Effectively, I am self-supervising therefore I take breaks when I think fit, I am not subject to criticism with regard to work output"*
>
> Respondent 168
>
> *"We have no set breaks for morning/afternoon sessions, just a ½ hour lunch"*
>
> Respondent 210

A trend was noted in the continuity of service and cross-cover of reporting provision during annual leave, which some respondents (29%; *n*=64/221) stated employers never pre-arranged or planned cover. Conversely, 34% (*n*=75/221) of radiographers were allowed to participate in additional out-of-hours sessions to reduce reporting backlogs after periods of leave to support the service.

Resources and Equipment

On equipment, resources, and working conditions, a high number of radiographers (88%; *n*=187/212) indicated they had access to appropriate Picture Archiving and Communication Systems (PACS) reporting monitors. Despite this, not all radiographers (40%; *n*=84/211) had a dedicated office to report in, with a quarter (25%; *n*=51/204) reporting in open plan or shared spaces. Almost half (48%; *n*=102/212) did not have a dedicated chair, desk, telephone or IT equipment during reporting. However, a large number (69%; *n*=146/212) of the respondents had access to and used speech recognition software.

Measure of performance

It is stated throughout DoH,[30] SCoR,[20] HCPC, [32] and RCR[24, 27] standards on advanced practice that clinical governance, auditing, recording of discrepancies and attending of multidisciplinary team meetings (MDTMs) are all held as established benchmarks for quality assurance for reporting radiographers. Data obtained under the performance measure category reflected only 36% (*n*=77/216) of the questioned reporters indicated that they regularly audited their workload. Possible impeding factors included 33% (*n*=74/221) of participants were not accommodated protected time for auditing within their shift. Although 87% (*n*=227/261) of radiographers had a requirement to attend MDTMs, of which 53% (*n*=84/158) were not allocated time to prepare materials (images/reports) for discussion or feeding back of information. Further responses conveyed concerns that several radiographers (26%; *n*=58/219) were not given time for any clinical governance responsibilities connected to their practice. When asked if they were consulted when their department adjusted imaging protocols for the modality they reported, which would directly affect the image quality of their practice, 34% (*n*=72/211) reported they were. Furthermore, 68% (*n*=142/209) did state they received annual employee appraisals to review their ongoing performance.

Education and training

All clinical advanced practice positions require participants to engage in CPD linked to the career framework of the SCoR,[20] HCPC,[32] and DoH.[30] When reviewing mandatory CPD as a requirement of the HCPC registration,[32] 29% (*n*=65/221) of respondents stated they were not allocated any protected time for CPD activities. However, 37% (*n*=78/211) reported having departmental support to access external CPD events. One of the deciding elements in study day attendance was who funded the CPD, with 44% (*n*=93/210) having available departmental training funds for CPD. Yet some respondents (30%; *n*=62/208) were routinely required to provide a business case first before a decision was made to allow access to training funds.

On questioning whether respondents were given internal departmental support (radiologist mentor) post-training and in daily clinical practice, as recommended by the SCoR.[8] Just over half (55%; *n*=125/227; $X^2 = 4.6$; $p < 0.308$) of the survey participants responded as not being provided with any mentor support in their advanced practice role. However 78% (*n*=180/231) of respondents agreed, this would provide a safe and supportive working practice.

The training and educational activity questions were not restricted to just the practitioners CPD, as many advanced practice standards require the role to include knowledge exchange activities with other professional groups. Included in the scope of practice of many reporting radiographers' duties is a requirement to teach training medical practitioners and emergency nursing professionals in image interpretation. Unfortunately, some respondents (31%; *n*=68/216) who were required to perform this task were not allocated time during shifts for this activity and were expected to carry out this duty outside of their paid rostered duties.

Discussion

The returned surveys allowed a comparison of the responses to the professional guidelines, although due to a small sample size it was not always possible to perform Chi Square calculation of independence. Review of the first category on the scope of practice found the questionnaires obtained data that reflected a broad variation on having a defined and explicit scope of practice. The data appeared to contrast at times to many standards, including professional body requirements[8] and the responsibilities detailed specifically under the Agenda for Change and Knowledge and Skills Frameworks,[30] and the Service of Diagnosis of Illness (Section 3(1) and Section 5(1)(b) of the NHS Act 1977.[41] The response data inferred that not all radiographers were consistently allocated weekly reporting sessions. The RCR[24] specify that any reporting practice involves direct clinical care and should have routinely scheduled reporting sessions to support adequate service delivery, including cross-cover provision or the requirement to provide additional 'out of hours' reporting sessions to resolve reporting backlogs.[24]

The results obtained on the category of resources, equipment, and working conditions, demonstrated not all radiographers had parity of access to suitable PACS display screens of recommended standards on spatial resolution and contrast as detailed in best practice guidance.[28] The environment to report within should adhere to best practice guidelines[42] such as an adequate workplace, IT resources, lighting,[29] heating, air quality, and reduction of extraneous sound. This environmental recommendation not only would provide an appropriate confidential setting, but could increase concentration and reduce the risk of errors in reporting. There is evidence for the potential for errors to occur through eye strain,[34] which conceivably may affect those radiographers not allocated rest breaks during long reporting sessions. It is worth noting that by law, the Working Time Regulations,[42] which applies the European Working Time Directive[43] (Article 10 and 11) requires an adequate uninterrupted rest period between shifts, to provide a period of rest away from the glare of a computer monitor.

The response to the third category on measures of performance allowed comparison of the 21% that regularly audited their work against the SCoR[8] and RCR[24] quality improvement and governance frameworks that require periodic audit and/or peer-review for quality and error review. The RCR[2] also advise that regular evaluation of the nature and number of examinations be audited. Acknowledging the workload achievable during a reporting session is variable, not just by ability, but by environmental interruptions[24] and equipment resources. The RCR[24] suggest a normal 'hot-reporting' session is likely due to its nature to be repeatedly interrupted, thus be less productive and produce lower reports per session (but provide a valuable service). Whereas, an uninterrupted 'cold reporting' session would achieve higher productivity of reports. Other factors that potentially impede productivity per session include the modality being reported by the radiographers. With each imaging technique having a different level of complexity and volume of data per examination, which can be time-consuming and complicated to retain a level of quality against punctuality of reporting. The RCR use the Gishen Ready Reckoner[26] to provide indicative modality based estimates of the amount of reports per hour of uninterrupted time, which is comparable to the amounts identified within this survey. Collective learning from audit discrepancies, error, and MDT meetings is advocated to improve patient safety,[25, 27] which the data suggested only 68% of respondents attend these meetings. Accompanying data revealed only 53% had allocated time to feedforward or back images/reports, as opposed to the RCR[27] and SCoR[25] recommendation of time be assigned to the preparation of materials for discussion and feedback of inquiries to improve service delivery.

The fourth category of education and training indicated mixed organisational support that did not consistently conform to SCoR[8, 25] and RCR[24] principles of CPD education and training activities, regular reviews and appraisal of advanced practice roles. The RCR and SCoR Team Working document[7] underlines the guiding values and beliefs that the establishment of appropriate supervision could provide a safe, efficient and practical service with safeguarding precautions, which is an important governance issue[7-8] that clinical imaging managers are collectively responsible for establishing and maintaining. The SCoR and RCR[8] advise that working in isolation without support is recognised as poor practice and potentially unsafe.

It is important to consider the impact of the outcomes of this small scale research which may be minor in practical terms (formal assessment and causal expectations), but studies in this area are important to help guide discussion on future practices. The provable effects of these results beyond academia will mostly be demonstrated in the contribution of this and similar papers in this area within the growing evidence base of implementation of advanced practice standards. The role of research in this area is to engage with professional bodies who are committed to improving future practice and advanced role guidelines through continued re-evaluation of the drivers and barriers to safe and competent practice.

Limitations

The constraints of this data suggest further research with a larger sample group to observe if the scale of variability is affected by factors of geographic location (urban vs. rural), size and type of hospital (district general or speciality), and experience of the reporter. Additionally, it would be of interest to know what, if any, the effect of increased support (mandatory auditing, mentorship, protected time for CPD) had on reporting. What a standardised approach would bring to the productivity of reports and the impact of future best practice guidelines to clinical reporting practice. At present with no published register of radiographers in advanced practice reporting roles, the population to sample is unknown and difficult to access, this factor will reduce the generalisability of these results to the population.

Conclusion

A sample group of reporting radiographers working in advanced practice roles were engaged through on-line survey methods to produce data on how professional body best practice policies and guidelines are currently being implemented in clinical practice. The results of the data collected, identified specific trends in the sample group on defined scope of practice, and the level of organisational support. It was implied from the varied responses on equipment and resources provided to perform the role, that best practice guidance on resources should be considered in future frameworks and policy to support safe working practices.

The diverse responses to the survey suggest adherence to recommended best principles in reporting were not consistent within this sample group. The main trends noted from the survey data centred upon on parity of support, equipment, scheduled sessions, audit mechanisms and cross-cover of service provision.

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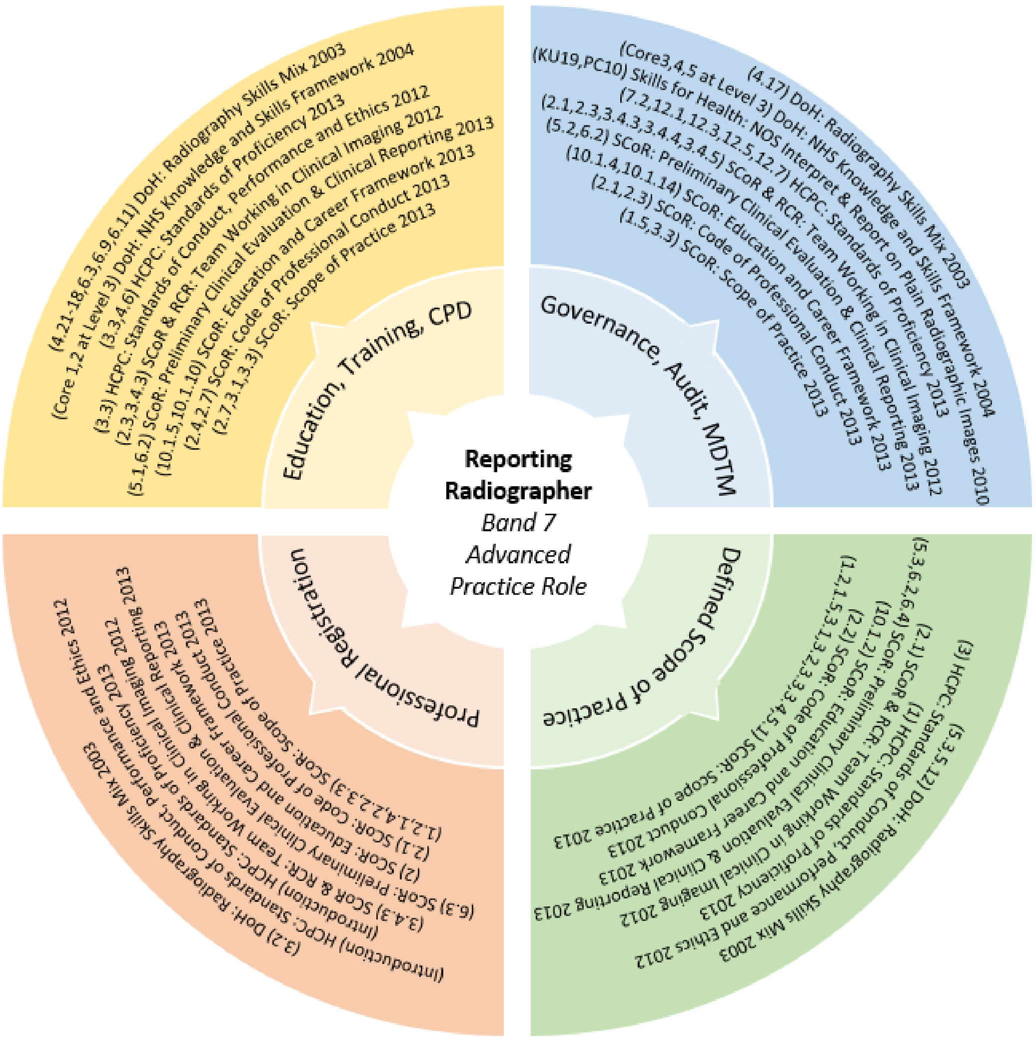
Appendix 1: Advanced Practice basic threshold standards.



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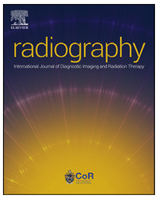

An evaluation of CT head reporting radiographers' scope of practice within the United Kingdom

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ABSTRACT

Introduction: This study investigated the scope of practice of CT head reporting radiographers in the UK, and to compare adherence to professional body standards.
Methods: An online questionnaire was utilized applying both multiple-choice and response (closed questions), and qualitative open question free-text responses. The 30 questions covered four key areas of demographics, the scope of practice, referrals, and ongoing competence, as described in professional body national guidance standards. The questionnaire was disseminated (convenience sampling) via Twitter and email to the National CT Head Reporting Special Interest Group. Responses were transcribed and coded; the results applied descriptive statistics to summarise observations of the study sample.
Results: The sample of participant response data analysed was $n = 54$. Most respondents were from England, with a postgraduate certificate award in clinical reporting, and a mean length of 8.3 years of reporting experience. The accepted referral pathway included a wide range of medical and surgical specialities, including both in and outpatients and acute and chronic pathways. Furthermore, 96.2% of the sample had a scope of practice that authorised referral recommendations to a broad and inclusive group of medical and surgical teams, and if required further or repeat diagnostic imaging. To maintain quality and evidence of ongoing competency, all radiographers were involved in audit cycles.
Conclusion: The data collected confirmed the reporting practice within this sample group aligns to national recommended guidance. The data provided key information on the range and variation of individuals scope of practice within age restrictions of patients, examination types, referral teams, and ongoing competency practices.
Implications for practice: This paper details the scope of practice of CT head reporting by radiographers and the contribution made to the healthcare sector.

Introduction

Computed Tomography (CT) is a common medical imaging examination in the United Kingdom (UK). The National Health Service (NHS) England[1] estimates that on average 0.49 million CT examinations a month have been undertaken in the last 12 months. The Royal College of Radiologists (RCR)[2] further advise CT imaging has increased by 54% over the last five years. The RCR workforce consensus[2] indicates a 23% radiologist workforce shortage in the UK, resulting in only 2% of UK NHS radiology departments being able to meet national reporting deadlines. In 2003 the Department of Health[3] introduced the skills mix initiative to support service delivery to meet the demand for urgent and timely reporting of medical imaging through implementing reporting radiographers into NHS clinical practice. The initiative was further endorsed by the RCR and Society and College of Radiographers (SCoR) team working on reporting guidance.[4] The latest data for managing the reporting demand indicates that 84% of UK NHS trusts now employ reporting radiographers across a range of imaging modalities.[2]

In recent years there has been criticism levied at the reporting radiographer service, citing that radiographers' reports are “observational and descriptive, without any depth of medical interpretation in the context of the individual patient concerned: such reports are therefore of little, or no, added value to the referring doctor in imaging studies of any complexity (such as chest x-rays or CT or MR scans)”.[5]

The literature on CT head reporting by radiographers in clinical practice post qualification is limited. The majority of papers have concentrated on training and endpoint assessment,[6–10] or drivers

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and barriers to training.[11] To date, the specific role of CT head reporting by radiographers has been supported by both the SCoR[12,13] and the Care Quality Commission[14] and the National CT Head Reporting Special Interest Group (CT Head SIG).[15] The CT Head SIG aims, and objectives include investigating how the advanced practice reporting role is embedded within clinical practice, promotion of the role and profile, and sharing best practice and national standards of reporting radiographers.

This study aims to investigate the scope of practice of the CT head reporting radiographer role in the UK and to gain a comparison to professional body standards and guidance.

Method

The study received ethical approval from the institutional ethics and governance approval panel (Ref:18/H&W/25C). A pilot questionnaire was trialled ($n = 4$) for online access, reliability, validity and appropriateness of questions. The pilot was based upon critical themes identified from four national guidance documents[15–18] recommendations on a scope of practice for radiographer reporting roles should be implemented. The questionnaire instrument was refined from the pilot testing and was themed into key four areas (comprising thirty questions in total) on demographics, the scope of practice, referrals, and on-going competence (Table 1). The online questionnaire utilised both multiple choice and multiple response (closed questions), and qualitative open question free text response (to allow participants to provide their preferred answers based on their local clinical practice variation) to reduce response bias. The questionnaire was hosted online through a third-party software provider (Online Surveys (Jisc) 2019, Belfast, UK). The application of a self-administered questionnaire further reduced social desirability bias in responses.

Accessing the UK population of CT head reporting radiographers to distribute the questionnaire too was problematic. There is no mandatory register of all the individuals practising CT head reporting held by any professional body. Convenience sampling of the questionnaire was applied due to the restriction on available data of the population being sampled, and as such, the study acknowledges this as a limitation. Dissemination of the online link to the questionnaire with information background sheets and consent forms were circulated via email to members of the CT Head SIG through gatekeeper access via the chair of the CT Head SIG. Additional advertisement of the study via social media (Twitter, 2019, San Francisco, USA) during May and June 2019 promoted the study and questionnaire. Social media platforms have been evidenced to engage with radiographers to discuss and debate professional development activities and overcome issues of geographical location, speed and ease of access.[19,20] Eligibility criteria required participants to be NHS CT head reporting radiographers within the UK.

Further confirmation of consent was required at the start of the online questionnaire to confirm participants had read and understood the study information sheet before starting. Anonymised free text data responses were coded using text search software analysis (NVivo 12, QSR International 2018, Victoria, Australia) to group common themes in responses and identify keywords, and map reoccurring prominent phrases from the qualitative data. The quantitative responses applied descriptive statistics (Microsoft Excel 2019, Washington, USA) to summarise observations of the study sample. The results were displayed in central tendency bar chart histograms, mean, median, mode; and measures of variability and dispersion using standard deviation (SD), Standard Error (SE), range, and sample variance.

Results

Sample demographics

The total amount of individuals that completed the questionnaire was $n = 58$, two were removed due to partial completion, one set of data was removed due to ineligibility (outside the UK), a further was a historic response of no longer reporting, the final sample size was $n = 54$. There was no returnable data on whether the participants responded via the CT Head SIG email or Twitter advertisement of the questionnaire. A breakdown of the Twitter responses is shown in Table 2 with the amount of Impressions (reach of the tweet advertisement of the questionnaire to individual Twitter accounts) the amount of Engagements (the number of times individuals interacted with the Tweet advertisement) and Link Clicks (the number of individuals who accessed the questionnaire via the Twitter link, although this does not evidence submission of completed questionnaires).

Subgroup locations of the participants completing the questionnaire displayed 94.4% ($n = 51/54$) were represented within England, with 3.7% ($n = 2/54$) of the proportion of respondents in Northern Ireland, and a single respondent from Scotland (1.9%; $n = 1/54$), no responses were returned from Wales. A detailed location breakdown is presented in Fig. 1, displaying the largest proportion of responses came from the South East and North West of England. Further specifics of the demographics, detailed 92.5% ($n = 50/54$) were in NHS employment in England, 1 (1.9%) participant came from an NHS Board in Scotland, 1 (1.9%) participant came from a Health and Social Care Trust in Northern Ireland, and 2 (3.7%) declined to share their employer. The respondent's qualification award (Fig. 2) displayed a central tendency towards a postgraduate certificate qualification. An anomaly noted in the data is a high proportion of responses attaining masters level credits as an alternative to a full award. Factors leading to this outcome were not further explored to determine if this was additional training on-top

Table 2
Tweet analysis of questionnaire advertisement.

Date	Impressions	Engagements	Link Clicks to the Survey
13.06.2019	1305	34	2
06.06.2019	2562	30	3
31.05.2019	1183	41	8
24.05.2019	1899	23	5
20.05.2019	695	37	18
15.05.2019	1712	50	6
14.05.2019	1914	94	21

Table 1
Key themes selected from national guidance for the questionnaire.

Questionnaire Key Themes	CT Head SIG 2018[15]	SCoR 2013[16]	RCR 2018[17]	HCPC 2013[18]
Demographics	E3	2.0, 5.1, 6.1, 6.2, 6.3	1.0, 2.0	
Scope of Practice	SP1, SP2, SP3, SP4 L6a, AII	4.0, 5.3, 6.2	1.0	1.1, 13.5, 13.14, 13.15, 13.16, 13.21, 13.22, 14.7, 14.8, 14.10, 14.11, 14.12, 14.35
Referrals	SP7, SP8, L3, L5, AII		1.0, 2.0, 3.0, A1, A2	4.5, 8.1, 9.5, 11.2, 13.4, 13.8, 13.13, 13.22, 14.2, 14.14
On-going competence	KS2, KS3, KS4, KS6	2.0, 5.2, 6.2	1, A3	12.1, 12.3, 12.4, 12.5, 12.6, 12.7, 13.19

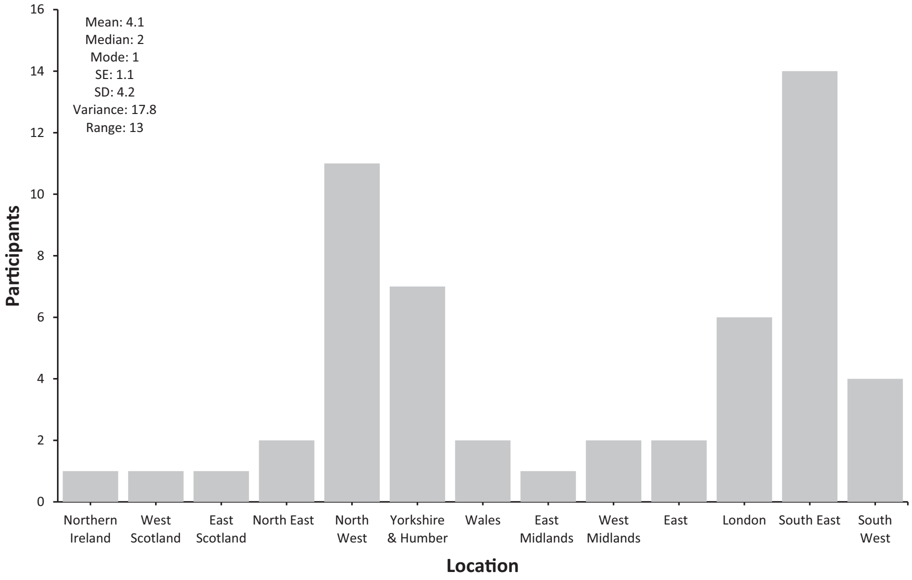

Figure 1. Regional location of participants (each participant chooses one option).

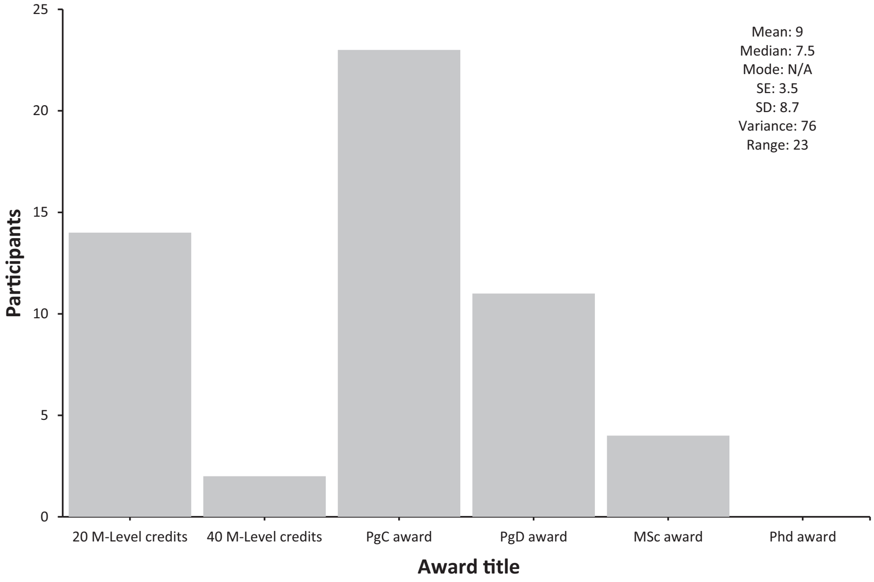

Figure 2. Reporting postgraduate qualification of the surveyed radiographers (each participant chooses one option).

of or supplementary to a previous reporting qualification or a standalone training course. The responses to the initial qualification in reporting CT heads (Fig. 3) displayed a wide range and variety with a mean response of 8.3 years' experience in this sample group.

Scope of practice responses

Exploration of the scope of practice disclosed 79.6% ($n = 43/54$) had an age restriction of the patient reporting workload detailed within their scope of practice, of which 98.2% ($n = 53/54$) of respondents reported adult examinations, and only 11% ($n = 6/54$) reported paediatric examinations (0–18 years). In addition to this, the responses further indicated 100% ($n = 54/54$) reported non-contrast enhanced scans, 68.5% ($n = 37/54$) reported venous contrast enhanced examinations, and 46.3% ($n = 25/54$) of the respondents reported arterial contrast examinations of the brain.

Further detail within their scope of practice reflected 40.7% ($n = 22/54$) of the radiographers identified anatomical areas/examinations that were excluded from their scope of practice. These included CT examinations whose field view of extended beyond the head or multiple CT examinations/multiple areas of anatomy scanned within the same attendance, which included facial bones, petrous bones, paranasal sinuses, orbits, mastoids and the cervical spine, and therefore the examinations were outside of their scheme of work to report.

Referral responses

The referral pathways that the radiographers accepted within their scope of practice included a broad and diverse medical community (Fig. 4). The peak distribution of responses leant towards General Practitioners as the most commonly accepted referral

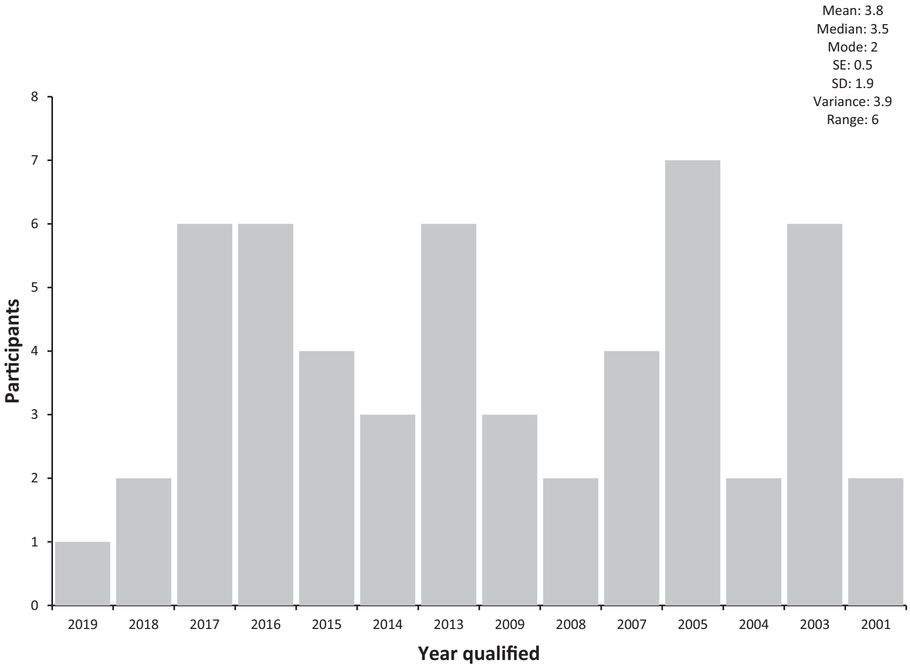

Figure 3. Year of qualification of respondents (each participant chooses one option).

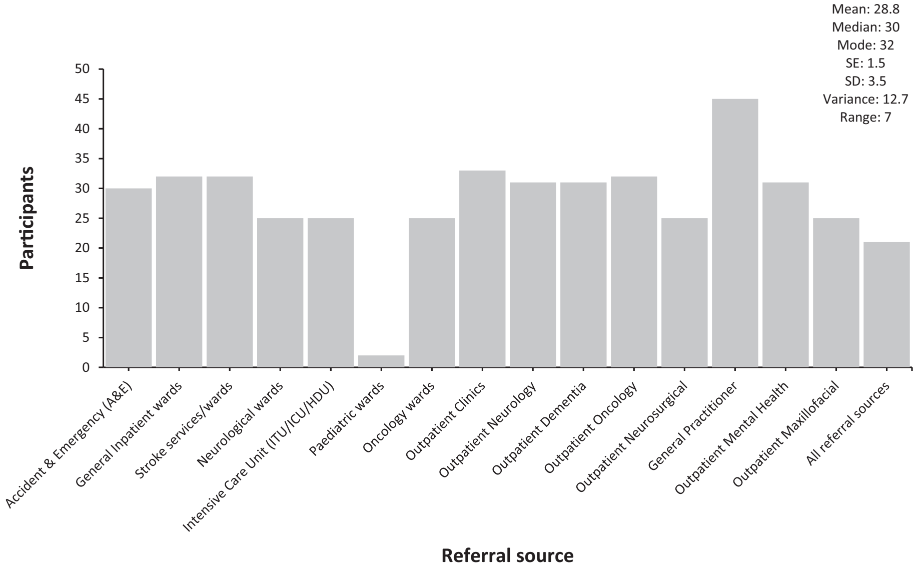

Figure 4. Agreed referral pathway written within the respondent's scope of practice (this was a multiple answer option; percentage of respondents who selected each answer category shown (if all chose a category it would represent 100% of respondent's choice).

source (83.3%; $n = 43/54$). The distribution (Fig. 4) displayed a wide outlier of choices in referral categories displaying a range of referral sources accepted within this study sample, and not a task specific or limited scope of referral practice.

The radiographers were further asked about their ability to refer on post examination reporting to assist the patient management and treatment. The data returned reflected 96.2% ($n = 52/54$) of respondents had a scope of practice that allowed them to refer for further (or repeat) imaging in their clinical reports. With 55.5% ($n = 30/54$) allowed to refer on their own accord and 40.74% ($n = 22/54$) allowed to refer on after discussion with a consultant radiologist. The choice of modality included within their scope of practice incorporated all possible radiological examinations, with cross-sectional imaging, the most popular (Fig. 5), potentially due to the type of neurological examinations reported.

Subsequent further inquiry on referral practices demonstrated 90.7% ($n = 49/54$) of the respondent's scope of practice authorised them to recommend onward referral to specialist clinical teams for input into the treatment and management of the patient. The range of clinical and surgical teams noted within their scope of practice is displayed within Fig. 6. These findings demonstrate the wide and varied medical and surgical teams that the radiographers interact and communicate their findings onwards to assist the patient's management and treatment pathway. The free text response

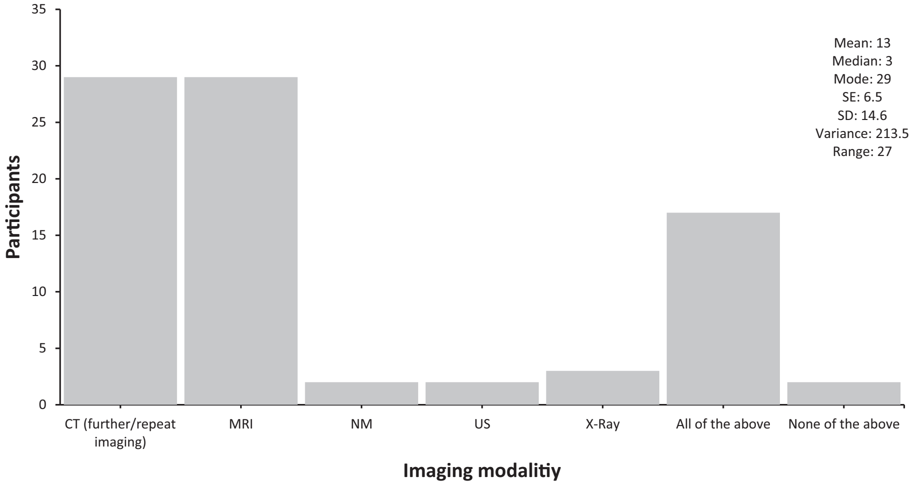

Figure 5. Referral onwards for imaging allowed within the scope of practice (this was a multiple answer option; percentage of respondents who selected each answer category shown (if all chose a category it would represent 100% of respondent's choice).

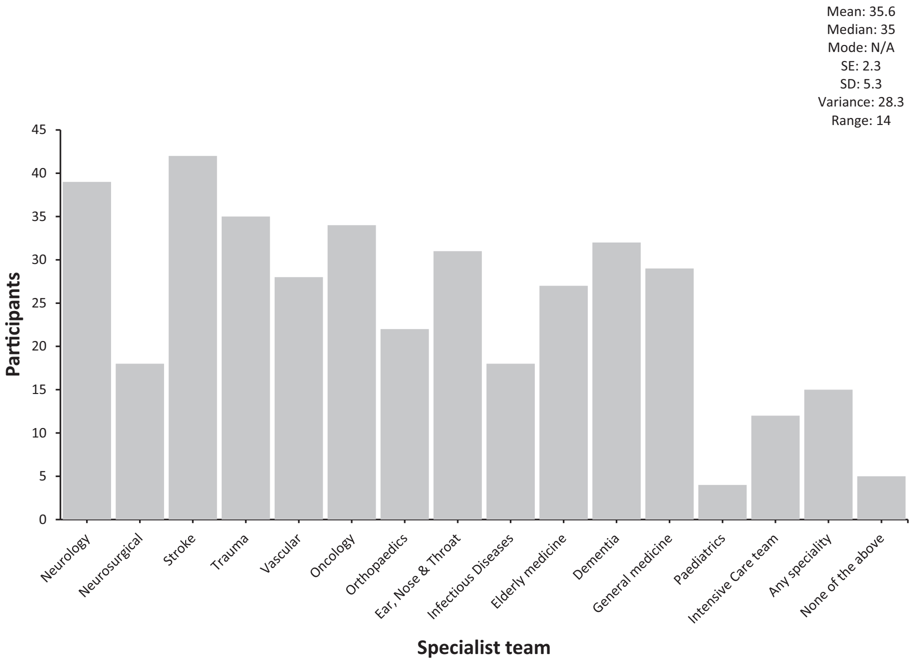

Figure 6. Referral onwards to a specialist team within the clinical report allowed from the radiographer's scope of practice (this was a multiple answer option); percentage of respondents who selected each answer category shown (if all chose a category it would represent 100% of respondent's choice).

eluded to the type of communication recommend in the treatment and management options, and common examples are displayed below:

“Equivocal CT for query subarachnoid haemorrhage suggest lumbar puncture if there are no contra-indications to the procedure for CSF sampling to rule out SAH”.

“Expeditious commencement of anti-viral therapy (Acyclovir) in suspected encephalitis”.

“An MRI brain scan with contrast is advised to characterise this complex lesion further”.

On-going competence responses

The questionnaire additionally investigated the respondent's on-going competency reviews to support quality assurance within their clinical practice. Of the radiographers questioned 88.8% ($n = 48/54$) received an annual performance review of their reporting role, and 98.1% (53/54) participated in routine audit cycles to confirm their reporting performance level. The pattern of the audit cycle in each respondent's clinical department varied (Fig. 7), with the most popular category voted as 12-month audit cycles. Furthermore, the radiographers were asked how many CT head cases were incorporated into each audit cycle (Fig. 8) the responses distribution indicated the category of more than 10 CT heads in each audit cycle as the most popular (59.2%; $n = 32/54$) in this sample.

Discussion

The sample of respondents was small, although the results highlight new and important data on the scope of practice of CT

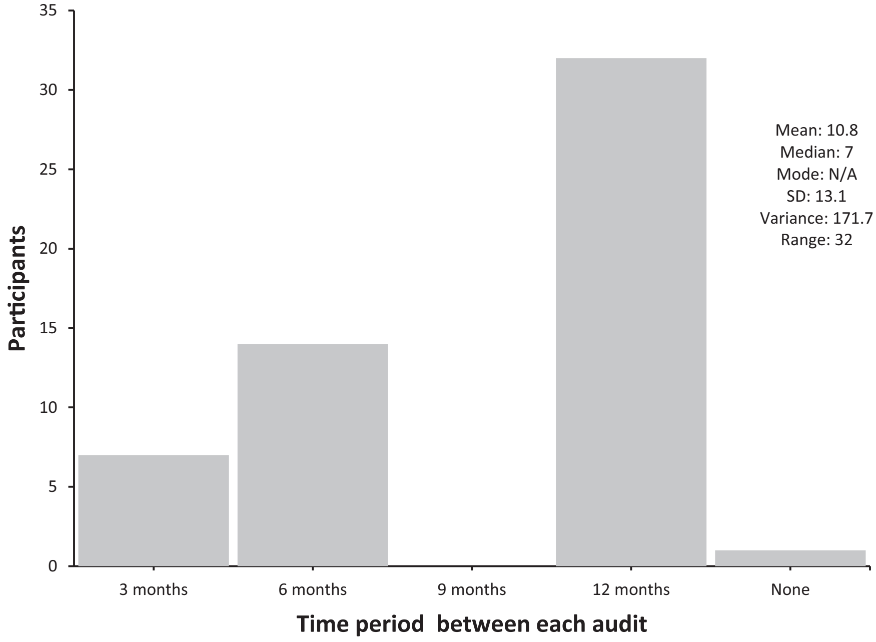

Figure 7. Audit cycle in months for each respondent (each participant chooses one option).

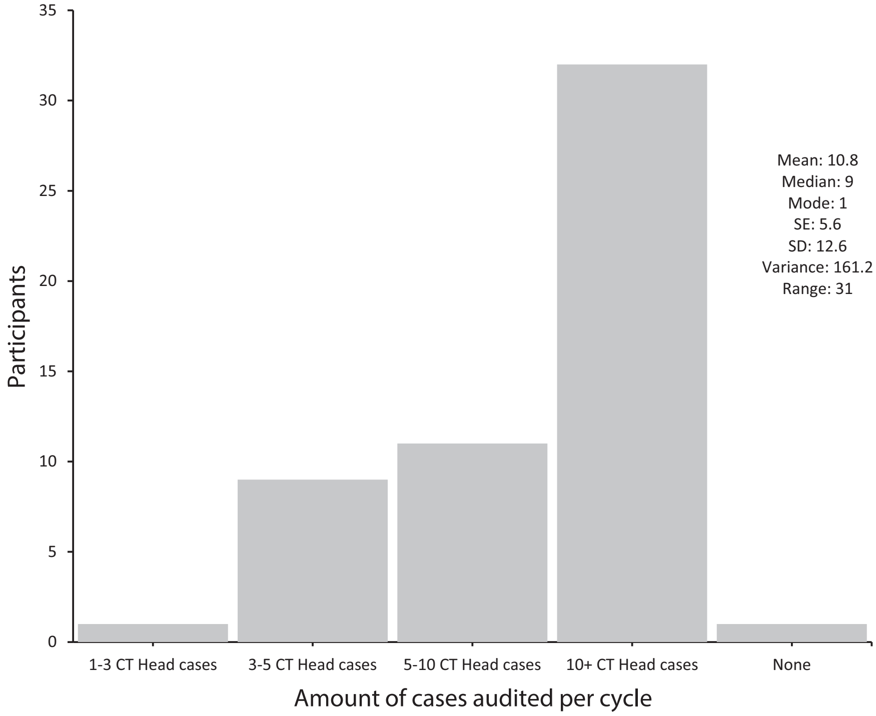

Figure 8. Amount of CT head cases included in each audit cycle (each participant chooses one option).

head reporting radiographers and provide some significance beyond academia to enhancing the evidence of reporting radiographers in the healthcare environment. The sample size in this study was smaller than a previous survey,[21] although the range and variance of both the qualification award (Fig. 2) and years of reporting (Fig. 3) increases the validity of the respondent's voice in this study as reflected by their years of experience and exposure to CT head reporting to be able to provide sufficient testimonials of their clinical practice. The recruitment would have been more robust if an accessible database or voluntary register of reporting radiographers was held by a professional body such as the SCoR. At present the only available system is an optional advanced/consultant practitioner accreditation register which applies to all higher-level clinical practice and not just reporting. The response rate to topics on application of an agreed and defined scope of practice and accepted referral pathways (100% compared to 74%[21]), audit completion (100% compared to 36%[21]) and annual appraisal of ongoing performance (100% compared to 68%[21]) reflect adherence to national guidance standards.[15–18] Further work on comparing practices between different services/individuals could expand upon the audit cycle practice to review caseload age ranges, pathology prevalence, range of conditions, and expand upon the exact number of cases routinely reviewed (especially if greater than 10, as noted in Fig. 8).

A key theme shown in the data on referral recommendations within the reports demonstrated a broader view of the variables of the scope of practice, with 90.7% (n = 49/54, Fig. 6) communicating findings onwards to be actioned. It was unclear why a small percentage of respondents do not refer on to specialist teams. Reasons could include the department protocol (potentially, some departments would prefer the original referrer to take responsibility for the patients' care pathway) or newly qualified reporters' confidence to communicate directly to specialist teams. The majority of radiographers that did refer evidenced that radiographers' reports are more than just ‘descriptive in nature’ and provide actionable recommendations and communications to and with a range of healthcare professionals to assist the management of patients post CT examination. Furthermore, they reflected adherence to RCR standards[17] of the description of the findings and diagnosis, and the suggestion of further imaging, patient management if appropriate. As well as conforming to the SCoR clinical reporting guidance recommendations[15,16] and the Health and Care Professions Council (HCPC)[18] requirements set out within the Standards of Proficiency to interpret medical images and data and record appropriate information to assist when further action is required.

Brealey[22] considered the logistical conundrum of how to evidence the effect of a radiographer's report on a clinician's judgement and patient outcome. This would require an observational follow-up study of the many factors involved within the written report of structure,[23] content,[24] and readability of the report,[25] to then relate these to the patient's records on treatment and management post CT examination. Although this is not as straight forward as it seems as follow-up studies post clinical report to measure the effects on patient outcomes are complicated. The imaging report could be correct, and referral onwards recommended to a specific surgical or medical management pathway, but the clinicians may choose a different treatment and management of their own opinion or assessment. Recently the Healthcare Safety Investigations Branch produced guidance[26] in collaboration with the RCR, SCoR and Academy of Royal Medical Colleges recommending clinicians act on all radiological reports (especially any urgent, critical or unexpected findings) and document the response in the patient's records. Observational studies may be possible in specific CT head pathways such as ischaemic stroke,[27] traumatic head injury[28] or subarachnoid hemorrhage[29] tracking patient medical records post CT scan and radiographer report to see if the clinician adheres to the recommended surgical[28,29] or medical[27] managements. However, physician judgements will always be multifactorial, and the imaging report is but one test in combination with medical histories, blood chemistry results, physical examinations, mechanism of cause in combination with potentially pre-existing chronic or acute conditions, clinical advice from medical/surgical teams and patient choice/consent. As such observational studies may not answer all potential reasoning of patient treatment and management decisions downstream from imaging reporting.[30–32]

The effect of radiographer reports on patient treatment and management options has been attempted in plain film reporting by radiographers.[33–37] Likewise in chest reporting by radiographers studies have endeavoured to establish if there is a measurable outcome effect through observational studies on chest x-ray reporting advising referral for same day CT lung cancer screening[38] or urgent respiratory medicine management.[39] Despite the small but growing studies evidencing outcomes, the current collective pool of studies on radiographer reporting demonstrates that the advance practice role is now beyond the threshold of being task specific and limited in scope.[40] Indicators of the impact and contribution to the healthcare sector of CT head reporting by radiographers are now cited and endorsed in stakeholder strategy and policy documents by the SCoR,[12,13] the British Institute of Radiology,[41] Health Education England,[42] NHS England,[43,44] and the UK independent healthcare regulator the Care Quality Commission.[14]

Limitations

Data from the sample ($n = 54$) within this study (drawn from the population) are not generalizable to the whole population of radiographers reporting CT head examinations within the UK; exact population numbers are unknown; thus, convenience sampling was applied via email to the CT SIG group and online media which introduces some inherent bias in the dataset. The CT Head SIG guidance on Scope of Practice[15] was developed by the CT Head SIG members, an acknowledgement that two of the 138 members of the CT Head SIG are SCoR employees introduces some bias of independence between the two groups. It is further acknowledged that not all CT Head SIG members are CT head reporting radiographers, the collective also includes radiology service managers, radiologists, trainee reporting radiographers, and radiographers that do not report but share an interest in the topic, thus the questionnaire response rate would not reflect the full CT Head SIG membership population.

Conclusion

The testimony and confirmation of CT head reporting by radiographers within the UK displayed in these findings demonstrate the progressive growth and establishment of the advanced practice within this modality and the associated additional reporting capacity and service delivery to benefit the healthcare system. Consideration of the practical relevance of these findings is reflected in the structured specific scope of practice which confirmed it aligns to national recommended guidance.[15–18] Information and data on CT head reporting by radiographers in clinical practice is sparse, this paper has the potential to increase the knowledge of its role and highlight key areas it contributes to in the healthcare sector which is transferable regionally, nationally, and internationally.

Conflict of interest statement

None.

Declaration of interest disclosure statement

There are no significant financial support/personal interest or beliefs that could affect objectivity or influence the study outcome.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radi.2019.09.001.

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An economic evaluation of introducing a skills mix approach to CT head reporting in clinical practice

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ABSTRACT

Background: Computed Tomography (CT) head examinations are a common diagnostic examination in National Health Service (NHS) acute hospital trusts. Current NHS England and Royal College of Radiologist (RCR) reports estimate the year on year increase of examinations to be 10%, with the designated workforce of radiologists disproportionate to the increase in demand of imaging reporting.

Objective: To determine an economic evaluation of cost, risk and feasibility of introducing skills mix CT head reporting by radiographers.

Design: Applying a PICO framework study to evaluate the patient workflow demand from retrospective audit data of CT head examination attendance ($n = 7266$) at an acute NHS district general hospital (DGH) to model an example workflow demand over 12 months. Reviewing potential outcome risk data (diagnostic thresholds), and feasibility (workforce capacity) of both interventions. The economic evaluation calculated hourly unit costs for comparison estimation of consultant radiologists and reporting radiographers using Netten et al.'s Ready Reckoner. Report unit costs were calculated utilising the Gishen's Ready Reckoner to estimate the uninterrupted time of reporting a non-complex CT report using RCR, Centre for Workforce Intelligence (CfWI) and Department of Health (DoH) estimates for both interventions.

Conclusions: The economic evaluation of introducing a skills mix reporting service model to the benefit of service delivery with the NHS has shown a potential £299,359–£124,514 per annum cost saving using a generic acute DGH workload model. Research into recorded discrepancy/error audit data for potential detrimental risk to patient outcomes identified a paucity of evidence, and recommends further research is needed.

Introduction

The National Health Service (NHS) England released the Five Year Forward View[1] in 2014 to consider possible future changes that could be implemented to improve the NHS. The recommendations are hoped to increase patient outcomes and satisfaction, and decrease service delays, with an emphasis on investment for local service changes. In radiology early models of skills mix working have emerged in service improvements projects but the Five Year Forward View[1] sees reshaping delivery of our services must include system efficiencies to reduce poor services, and backlogs.

The two key driving factors for change have been a flexible response to workforce shortages,[2–8] and demand for imaging that outstrips capacity.[9–11] With 22 million people attending accident and emergency departments every year (3500 more patients attending every day compared to five years ago[1]), systemic change in practice to cope with demand is a necessity. The NHS Imaging and Radiodiagnostic activity 2013/14 report[9] findings estimated the number of computed tomography (CT) examinations from April 2013 to March 2014 were 5.2 million, with a 10% growth of examinations from the previous year,[9] an increase of 43.1% over five years,[12] and 160% increase over a 10 year period.[9] The Centre for Workforce Intelligence (CfWI)[10] expect the overall demand for imaging to increase driven by many factors including growing/ageing populations, increase in cancer diagnosis and chronic illness, screening programmes, 24/7 working hours, and future imaging techniques introduced into clinical practice.

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The fifth Royal College of Radiologists (RCR) Workforce Report 2012,[3] recorded the number of united kingdom (UK) registered radiologists as 2997 (4.7 working time equivalent consultant radiologist per 100,000 population in the UK), with a current deficit of 283 unfilled posts in the UK and a predicted 17% retirement rate in the next 5 years.

The RCR[13] recommend a formal report for diagnostic examinations within 2 days, but acknowledge through workforce shortages that this is not occurring,[12] causing delays in cancer and serious illness diagnosis, hospital stay and the subsequent increased registration of radiology departments to NHS risk registers.[13] In October 2014 a RCR survey[13] highlighted a month delay in results in the 25% of NHS trusts surveyed, this survey was repeated in February 2015 with 71% of surveyed trusts having delays of more than a month, with over 2883 unreported CT scans, estimated for all trusts to be up to 3,693.[13]

Current Health and Care Professions Council (HCPC)[14] estimates there are 29,711 radiographers registered within the UK, which is an increase above the predicted radiographer workforce by the CFWI[15] of 19,830. A study by Clarke et al.[16] showed that two UK universities in 10 years had trained 114 radiographers to report CT heads, and it is known at least 9 UK universities have run CT head reporting courses for radiographers. The last survey by the Society and College of Radiographers (SCoR) of radiographic practice in 2012,[17] recorded at least 17 UK hospitals had started using CT head reporting by radiographers. With the SCoR promoting the national CT head reporting special interest group (CTSIG) Scheme of work[18] to report examinations from a wide scope of referral sources including accident and emergency, inpatient, outpatient and general practitioner requests.

Methodology

In order to define the perspective of the study, and the key drivers of cost effectiveness (capacity and demand, benefits and risks) a PICO framework was adopted. Comprising of P = the patients having CT head imaging; I = Intervention of radiographers reporting of CT head examinations; C = comparison to existing intervention of radiologists; O = outcome comparison of current and alternative service provision through costs, savings, and risk outcomes.

The study received university research ethical and governance approval to calculate a deterministic scenario based upon costs and risks of the current and new intervention of reporting against data from a retrospective audit of CT examination attendance at an acute NHS district general hospital (DGH) and national tariffs. Using a defined time horizon of 12 months (Table 1), identified the key resource demand for CT examinations (n = 19,578), and in particular CT head examinations (n = 7266).

Decision tree modelling illustrated the process mapping of the current intervention (Table 2), allowing evaluation of costs and outcomes from each intervention for internal validity. Applying the audit data allowed external validation of the model as an example of workflow demand in a generic DGH. A decision tree was chosen over conventional Markov models as data for chronic returning patients was not available to consider all feasible transitions of patient's health states or cohorts of particular disease categorised patients.

Patient group

The retrospective data from the audit identified n = 7266 CT head examinations (Table 1) from a wide range of referral pathways including In and outpatients, accident and emergency, stroke wards, dementia clinics, and general practitioner sources.

The current intervention

The NHS at present utilises radiologists to report CT head examinations, but the drivers for change from this service include the low workforce numbers of UK registered radiologists.[12] To reach comparable radiologist levels with the rest of the European Union (EU) countries, the RCR estimated it would require an 82% increase of consultants.[10]

The CfWI report on Clinical Radiology[10] commissioned by the Department of Health (DoH) with multiple stakeholders including the RCR and SCoR reviewed the RCR 2012[11] report for the Medical Programme Board and the Joint Working Group on Speciality Training Numbers. Recommendations included (but not implemented) an increase of 60 trainees per year due to the increasing demand of imaging, and the use of radiographers to effectively support the future expansion of radiology.

Table 1
Audit results of CT demand at an average sized generic DGH (2014–2015).

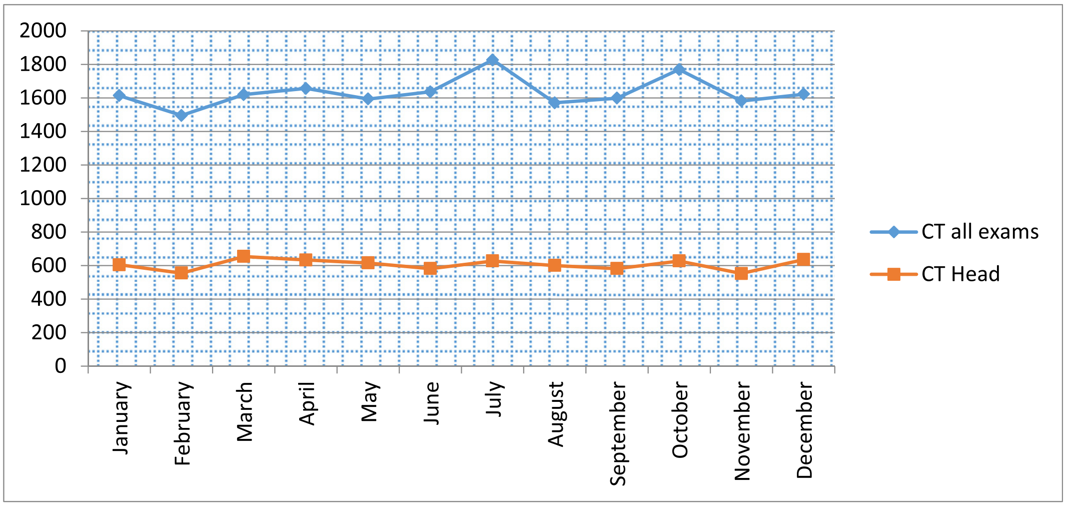
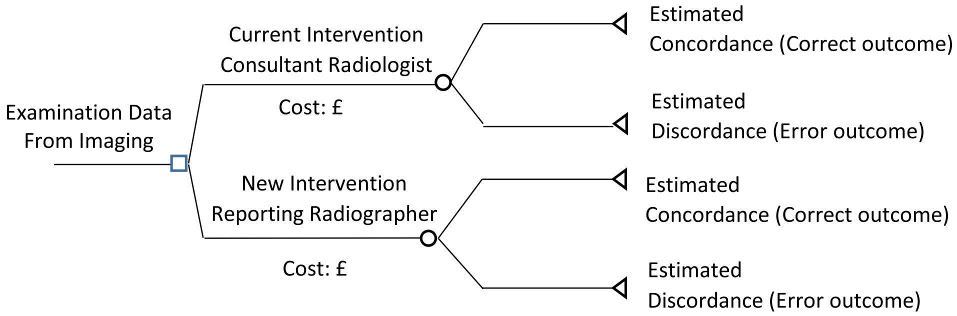


Table 2
Decision tree populated with risk probabilities. Square nodes = decision nodes, round nodes = chance points, triangular nodes = terminal points.



Unit costs and discounting

To determine an average hourly rate for radiologists, Netten et al.'s Ready Reckoner for staff costs in the NHS[19] and the Personal Social Services Research Unit (PSSRU) Unit Costs of Health and Social Care 2014[20] were adopted. The salary was based on a full time equivalent (FTE) mean of NHS medical consultant wages.[20] An additional 33.5% was added to reflect payments for activity such as overtime, shift work, geographic allowances,[20] National Insurance (NI) contributions,[21] and employer's contribution to superannuation.[22] The costs for education and training use the PSSRU[20] standard estimation approach to review the components of training, tuition fees, clinical placement costs, infrastructure (books, journals, computers), and lost production costs of staff training days.

Costs included the discounting system used by PSSRU[20] and HM Treasury[23] to convert all costs and benefits to ‘present values’ to compare, using a 3.5% discount rate. Allowing a net present value of an intervention to be calculated which is the primary indicator used by the UK government to justify action. This is the adopted system in use by the National Institute for Health and Care Excellence[24] (NICE) for all DoH[25] assessment and appraisals of health technologies, techniques, and screening programmes. The hourly unit cost of a consultant radiologist (2014–15) was calculated at £156 (Table 3).

The new intervention

The RCR with the SCoR have jointly published guidance[26] to promote the collaborative skills mix of radiographers and radiologists to work in complimentary reporting roles (not substitution or replacement of roles) to support service shortages. The SCoR Scope of Practice[27,28] legally entitles radiographers with accredited education, training and competence to report a wide range of diagnostic imaging examinations. The CfWI[15] have predicted an increase of 17% (to 19,830) of radiographers from 2012 to 2016, currently the HCPC[14] have 29,711 radiographers registered which is above the projected increase of workforce by the CfWI,[15] helped in part by Health Education England (HEE)[29] increasing educational commissioning.

The average UK radiographer unfilled vacancy rate was 5.1% at Band 7 reporting level[30]; the SCoR[30] estimate 3662 radiographers are in advance practiced and 86 in consultant roles (including reporting), with a further 1288 in postgraduate training.[30]

Unit costs and discounting

To calculate an hourly rate for a reporting radiographer, we used Netten et al.'s Ready Reckoner for staff costs in the NHS[19] and PSSRU Unit Costs of Health and Social Care 2014.[20] The salary was based on a FTE mean of Band 7 (point 30) of the Agenda for Change[31] wages for allied health professionals. An additional 7.2% was added to reflect payments for additional activities such as overtime, shift work, geographic allowances,[20] NI contributions,[21] and employer's contribution to superannuation.[22] The costs for education and training use PSSRU[20] standard estimation approaches to review the components of pre-registration and postgraduate training, tuition fees, clinical placement costs,

Table 3
Consultant radiologist hourly unit cost calculation.

	Costs and unit estimation	2014/2015 value	Notes
A	Wages/salary	(+) £87,060 per year	Medical Consultant average[20]
		£29,165 per year	33.5% Allowances[20] for overtime/shift work/etc
B	Salary oncosts	(+) £5012 per year	National Insurance Secondary threshold (ST) deduction[21]
		(+) £11,753 per year	Superannuation – NHS Pensions 13.5% – Tier 6[22]
	London multiplier	1.19 × (A + B) & 1.39 × G	Allow for higher costs of living in London[20]
	Non London multiplier	0.97 × (A + B) & 0.97 × G	Allow for lower costs of living outside of London[20]
C	Qualifications	(+) £72,197 per year	Taken from PSSRU,[20] using Netten et al.[19] costs from DoH and HEE Consultants = 2 foundation years, 6 speciality registrar years
D	Fees	(+) £420 per year	GMC[61]
E	Overheads, management, Administration and estates staff	(+) £20,048 per year	Taken from PSSU – NHS (England)[20] Management and non-care staff 19.31% of direct care salary
F	Non-staff	(+) £43,575 per year	Non-staff costs 41.97% of direct salary costs (include costs to provider – office, travel/transport, telephone, education, training, supplies, services, utilities of water, gas, electricity[20]
G	Capital overheads	(+) £8411 per year	Capital costs annuitised over 60 years (discount rate of 3.5%) based on PSSRU[20] New build and land requirements of NHS hospitals (adjusted for both treatment and non-treatment space)
H	Working time	(÷) 42.4 weeks per year (÷) 37.5 h per week	PSSRU[20] calculated unit costs of 1589 h per year: 212 working days (minus sickness absence, and training)[20]
	Unit costs 2014/2015	**£156 per hour**	

Table 4
Reporting radiographer hourly unit cost calculation.

	Costs and unit estimation	2014/2015 value	Notes
A	Wages/salary	£35,891 per year	AfC Band 7 mean- point 30[31]
		£2584 per year	7.2% Allowances[20] for overtime/shift work/etc
B	Salary oncosts	(+) £4197 per year	National Insurance Secondary threshold (ST) deduction[21]
		(+) £3337 per year	Superannuation – NHS Pensions 9.3% – Tier 4[22]
	Inner London multiplier	£4117 – £6,342per year	20% of basic salary[31]
	Outer London multiplier	£3483 – £4439 per year	15% of basic salary[31]
	Fringe multiplier	£951 – £1649 per year	5% of basic salary[31]
C	Qualifications	(+) £6120 per year	BSc Diagnostic Radiography Tuition Fees, living expenses, clinical placement[20] and Postgraduate clinical placement[20] and Postgraduate Certificate in Clinical Reporting (CT Head) fees[62] – Expected annual cost at 3.5%
D	Fees	(+) £70 per year	HCPC[63]
F	Overheads management, administration and estates staff	(+) £8385 per year	Taken from PSSU – NHS (England)[20] Management and non-care staff 19.31% of direct care salary
G	Non-staff	(+) £18,225 per year	Non-staff costs 41.97% of direct salary costs (include costs to provider – office, travel/transport, telephone, education, training, supplies, services, utilities of water, gas, electricity[20]
H	Capital overheads	(+) £8411 per year	Capital costs annuitised over 60 years (discount rate of 3.5%) based on PSSRU[20] New build and land requirements of NHS hospitals (adjusted for both treatment and non-treatment space)
I	Working time	(÷) 42.4 weeks per year	PSSRU calculated unit costs of 1589 h per year: 212 working days (minus sickness absence, and training)[20]
		(÷) 37.5 h per week	
	Unit costs 2014/2015	**£53 per hour**	

infrastructure, and lost production costs of staff training days. A 3.5% discounting rate was applied and the hourly unit cost of a band 7 reporting radiographer (2014–15) was calculated at £53 (Table 4).

Comparison of costs per intervention

Using the estimated unit cost per hour of both interventions, calculations of cost per examination for both interventions can be approximated. The RCR activity reporting guidelines[32] calculate time per test for reporting, which is the measure for setting workload standards in radiology (suggesting a maximum of 50% of time spent reporting examinations). The RCR acknowledged that in attempting to find one method to model the costings for reporting was difficult and each proposed system had limitations, the RCR opted to calculate work output using the Gishen's Ready Reckoner.[32] The RCR modality-based method estimated against 1 hour of uninterrupted time a range of 3–6 (non-complex) CT reports were possible,[32] with three variable time calculations of slow, medium and fast (20, 13.33 and 10 min per exam per report respectively). The CfWI and DoH[10] use weighted factors of 24, 16, 12 min per exam per report. The CfWI calculated each FTE radiologist was allocated 10.3 programmed activities (PAs); 2 PAs for non-reporting administration of paperwork, teaching, and other duties, with 8 weeks deducted for annual leave/study. Calculating 8 PAs over 44 weeks (the RCR[12] calculations use 10.3 PAs). The SCoR have no published costings of reporting radiographers' unit costs per non-complex CT examinations to compare against, so the RCR[32] and CfWI and DoH[10] systems have been adopted for comparisons (Table 5). No published studies were found on the time taken for radiographers to report CT head scans, the study for arguments sake reverted to the evidence of previous published studies from academic[33] and clinical[34] environments that used timed reporting of CT head case banks (same caseloads) on radiographers and radiologists producing near equivalent accuracy, agreement, sensitivity and specificity results.

Comparison of diagnostic thresholds per intervention

The risk of error in patient outcomes is an additional important measure to include in the evaluation of assessing interventions. This will determine if there is potentially an impact on patient outcomes (mortality, morbidity, functional status and quality of life) from the change of service delivery. The DGH audit data did not provide statistics from error/discrepancy meetings to assess the potential for detrimental risk to patient outcomes through reporting. A literature search[33] identified 45 studies comparing radiologist reporting levels; unfortunately the variation and quality of the studies methodologies and results did not provide sufficient

Table 5
Unit costs of per exam of current and new interventions using RCR[32], CfWI and DoH[10] calculations.

Non-complex CT report	Configuration	Cost per hour	RCR[33] slow report (20 min)	RCR[32] medium report (13.33 min)	RCR[32] fast report (10 min)
Current intervention	Radiologist reporting	£156	£52 per patient/report	£34.66 per patient/report	£26 per patient/report
Non-complex CT report	Configuration	Cost per hour	CfWI/DoH[10] slow report (24 min)	CfWI/DoH[10] medium report (16 min)	CfWI/DoH[10] fast report (12 min)
Current intervention	Radiologist reporting	£156	£62.40 per patient/report	£41.60 per patient/report	£31.20 per patient/report
Non-complex CT report	Configuration	Cost per hour	RCR[33] slow report (20 min)	RCR[32] medium report (13.33 min)	RCR[32] fast report (10 min)
New intervention	Radiographer reporting	£53	£17.66 per patient/report	£11.77 per patient/report	£8.83 per patient/report
Non-complex CT report	Configuration	Cost per hour	CfWI/DoH[10] slow report (24 min)	CfWI/DoH[10] medium report (16 min)	CfWI/DoH[10] fast report (12 min)
New intervention	Radiographer reporting	£53	£21.20 per patient/report	£14.13 per patient/report	£10.60 per patient/report

Table 6
Estimated mean diagnostic thresholds of current and new interventions.

	Configuration	Agreement range %	Sensitivity range %	Specificity range %
Current intervention	Radiologist – reporting	66–97.3%[34–40]	80–86.7%[34]	86.7–93.3%[34]
New intervention	Radiographer – reporting	88.1–95%[34,35]	82.3–99.8%[34,35]	90.1–100%[34,35]

detail, sample size, and pathology range. Reference standards varied, with some studies only providing accuracy/agreement levels, mostly without confidence intervals, sensitivity or specificity. Only 5 papers supplied sufficient details of results to provide a reference level for radiologists reporting CT head scans.

Observer variation studies from a number of published sources comparing against set reference standards have identified radiologist agreement levels range from 66% (Briggs[35]), 84% (Schringer[36] and Nagaraja[37]), 86.6% (McCarron[38]), 95% (Erly[39]) and 97.3% (Le[40]).

The introduction of reporting radiographers to interpreting CT head examinations has been reviewed previously by the author in an academic training setting[33] using timed examinations of same case load (and pathology) producing an agreement range of 88.1–90.8%, sensitivity of 97.4–99.8% and specificity of 93.1–97.7%.

A further multi-reader multi-centre study[34] by the author in a clinical environment of 6 NHS hospitals using 6 qualified and experienced CT head reporting radiographers and 2 radiologists used timed examinations of same case load (and pathology) to gauge results for both professions on CT head reporting. Demonstrated a sensitivity range of 82.3–95.1%, specificity 90.1–100%, and accuracy of 89.3–95%[34] for reporting radiographers. Radiologist's sensitivity range was 80–86.7%, specificity of 86.7–93.3%; and accuracy of 83.3–90%.[34] The findings indicated that radiographer's results are approaching and similar to the range of results identified for radiologists both in those studies and the literature review (Table 6), taking into account the possible variations present in the study designs.

Results (outcomes) of interventions to national tariffs and reference standards

The estimated monetary value of radiologist's hourly rate calculated against reporting radiographer's hourly rate using RCR[32] unit costs per non-complex CT report demonstrated a potential difference of £34–£17 per patient/report. Applying the CfWI and DoH[10] time range against radiologist and reporting radiographer's hourly reporting rate for comparison estimated a potential cost difference of £41–£20 per patient/report (Table 5).

Monitor 2014–15 direct access and outpatient diagnostic imaging services tariff (unbundled)[41] advise the cost paid by clinical commissioning groups for a CT scan (one area, no contrast) to be £77[41] with reporting, with cost of reporting alone £20[41] (NICE tariffs apply £78[42] for a CT head). Although there are regional variations of cost and local modifications,[43] this price is set out in the current Healthcare Resource Groups (HRG4) costs currently in use by the NHS national tariff payment system (2014/15) and is enforced by the Health and Social Care Act 2012[44] for NHS trusts, NHS foundation trusts and private providers. This is the dedicated price that local NHS providers and commissioners agree to cost at as set by the sector regulator Monitor,[45] to reduce anti-competitive practice that are opposed to patients interests. Opportunity costs modelling using the national tariff costs of £20 for a CT head report, compared to the estimated cost to report the examination by both interventions approximates the reporting radiographer option as cost effective for the NHS.

The results also allowed estimation over the observed range using the data ($n = 7266$) from the acute DGH 12 month audit to calculate potential savings of between £249,514–£124,757 could be achievable using reporting radiographers and the RCR[32] workload model (fast, medium and slow reporting times). Calculating the reporting radiographer's unit costs against the CfWI and DoH[10] reporting ranges provides a projected annual cost saving of £299,359–£149,679 (Table 7).

Discussion

The RCR[13] have reviewed and looked for solutions to the capacity demands of reporting services and have identified the use of radiographers as one of several solutions (including outsourcing, locums, additional catch up sessions, and review of current radiologists performance). The use of locums and outsourcing to commercial private companies is not without a large additional financial burden and may not be a sustainable policy for the future on current NHS financial and fiscal constraints.

The study has illustrated that both interventions have the diagnostic thresholds to achieve similar reporting standards. The societal cost/benefit to patients for the new intervention alongside the existing intervention could potentially together decrease reporting backlogs, evidence from previous studies in X-Ray[46–51], CT[16,52], ultrasound[52] and magnetic resonance imaging[52] support achievable increases in reporting turnaround times. The effects of introducing a system efficiency to improve the timeliness of examination reporting helps to enhance patient management and

Table 7
Potential unit costs of per annum of current and new interventions using DGH audit of workload against the RCR[32], CfWI and DoH[10] calculations.

Non-complex CT report	Configuration	Annual DGH workload	RCR[32] slow report (20 min)	RCR[32] medium report (13.33 min)	RCR[32] fast report (10 min)
Current intervention	Radiologist reporting	7266 CT head scans	Annual cost £377,832.00	Annual cost £251,839.56	Annual cost £188,916.00
Non-complex CT report	Configuration	Annual DGH workload	CfWI/DoH[10] slow report (24 min)	CfWI/DoH[10] medium report (16 min)	CfWI/DoH[10] fast report (12 min)
Current intervention	Radiologist reporting	7266 CT head scans	Annual cost £453,398.40	Annual cost £302,265.60	Annual cost £226,699.20
Non-complex CT report	Configuration	Annual DGH workload	RCR[32] slow report (20 min)	RCR[32] medium report (13.33 min)	RCR[32] fast report (10 min)
New intervention	Radiographer reporting	7266 CT head scans	Annual cost £128,317.56	Annual cost £85,520.82	Annual cost £64,158.78
Non-complex CT report	Configuration	Annual DGH workload	CfWI/DoH[10] slow report (24 min)	CfWI/DoH[10] medium report (16 min)	CfWI/DoH[10] fast report (12 min)
New intervention	Radiographer reporting	7266 CT head scans	Annual cost £154,039.20	Annual cost £102,668.58	Annual cost £77,019.60

treatment, which studies have shown[50,53,54] has a direct link to quality of care and patient satisfaction.

Healthcare economic evaluations review the trade off in any comparisons between two interventions of benefits, harms and costs, to review if the current treatment is dominated (more expensive and worse than an alternative) or if the new treatment is better but more expensive, or dominant (cheaper and better). There has been precedence in the past from studies in X-Ray[47,50,56–58], CT[59] and fluoroscopy[60] to establish the cost effectiveness of radiographers reporting. This study predisposes any additional cost between the interventions could not be appropriately calculated to Incremental Cost Effectiveness Ratios (ICER) or Quality Adjusted Life Years (QALYs) as the patient sample group data did not record the impact of the intervention on treatment and management plans, as evidence from discrepancy audit meetings were unavailable.

An additional limitation of this study recognises that a percentage of teaching hospitals use registrars in training to report CT heads and as such are a cost effective approach to reporting. In justifying why registrars were not included in this study, the DGH where the data was collected did not train registrars. Moreover the potential impact of using registrars could be questionable as they are often at different levels of experience and exposure to reporting so will still require some level double reporting at a greater cost of time and money.

Conclusion

The literature[9–12] available indicates that current practice is not conducive to future service delivery, a consideration of future workforce planning to cope with capacity and demand should include a whole-team approach to developing an effective service delivery with involvement from professional bodies, commissioners and stakeholders. The current scope and boundaries of imaging professions will need to consider sufficient overlap of roles to optimise and enable a modern skills mix of service delivery.

The economic evaluation of introducing a skills mix reporting service model has shown one potential option to assist the problems currently faced by NHS imaging department, with a possible £299,359–£124,514 per annum cost saving example using a generic acute NHS DGH workload model. Research into discrepancy/error audit data for potential detrimental risk to patient outcomes identified a paucity of evidence on eventual patient mortality/morbidity and quality of life, further research into this is recommended.

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Conflict of interest statement

The author is a senior lecturer on the MSc Clinical Reporting, MSc Medical Imaging pathways and programme director for BSc Diagnostic Radiography at Canterbury Christ Church University.

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