Planning the Radiology Workforce for Cancer Diagnostics

Report produced by the Workforce Observatory for the West Yorkshire Health and Care Partnership

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Executive Summary

The publication of the Delivery plan for tackling the COVID-10 backlog of elective care (NHSE/I, 2022:5) contained a number of ambitions, including that, by March 2024, 75% of patients who have been urgently referred by their GP for suspected cancer are diagnosed or have had cancer ruled out within 28 days. By March 2025, waits of longer than a year for elective care should be eliminated and 95% of patients needing a diagnostic test should receive it within six weeks. The report acknowledged the need to grow the workforce to achieve these ambitions and ensure a timely cancer diagnosis, while also proposing the use of digital technology and data systems to free up capacity.

To assist West Yorkshire National Health Service (NHS) organisations to meet these ambitions, this report presents the findings of a 'deep dive' that focuses on the role of radiology in meeting the ambitions of providing timely cancer diagnosis.

Aims

1. To understand current and projected demand for radiology expertise in cancer diagnosis in West Yorkshire.
2. To understand the current and projected radiology workforce in West Yorkshire and determine the gap between the projected radiology workforce and the required radiology workforce.
3. To identify possible solutions to assist in providing the radiology workforce required for West Yorkshire and explore their acceptability and potential impact.

Methods

A range of sources of data and methods were utilised. We examined publicly available quantitative data concerning cancer waiting times and diagnostic waiting times and activity and used this to forecast future cancer waiting times and diagnostic waiting times and activity. We examined data from Health Education England (HEE) regarding radiologists' and radiographers' workforce profile data for West Yorkshire, the number of radiologists completing training, and the number of radiographers graduating, and data submitted by West Yorkshire Trusts to HEE regarding their plans for growing their radiology and radiographer workforce. Interviews (N=15) conducted with radiology service managers, university academics and key strategic and operational stakeholders delivering radiology services were used to understand the current and future issues around strategic workforce planning, workforce changes and transformation, workforce roles and skills, training and education and service changes. A rapid review of the literature examining the impacts of artificial intelligence (AI) on the workload of radiology services was also undertaken. To put this work in context, we also reviewed relevant policy documents and reports. Alongside this, we consulted with the Yorkshire Imaging Collaborative (YIC) and the West Yorkshire Cancer Alliance (WYCA) and attended a series of workshops run by the Yorkshire Imaging Collaborative.

Results

Overall, the findings show that demand for radiology services is increasing and that both cancer waiting times and the waiting times for diagnostic tests increased, with a concurrent downward trend in activity that, if all else stays the same, is forecast to continue up to 2025. The cancer waiting times data indicate that patients were waiting longer and that their needs were not being met. Moreover, the proportion of people treated within accepted cancer waiting times decreased both nationally and within the West Yorkshire region from 2013. This was exacerbated by COVID-19 which caused a further decrease nationally and for the West Yorkshire region.

National data for waiting times for all diagnostic tests show a significant decline between 2006 and 2008, with a decrease in median waiting times from just under 6.0 weeks to approximately 2.0 weeks. Overall, waiting times remained stable until late 2020 when they started to rise with the longest median waiting times at just over 8.0 weeks in mid-2020. The total number of people waiting for radiology tests nationally is decreasing and is predicted to continue to do so, while in West Yorkshire the number of people waiting for radiology tests decreased until 2020 but has since been on an upward trend which is predicted to continue. Nationally, the total number of radiology tests is on an upward trend that is predicted to continue, while in West Yorkshire activity has been decreasing since well before COVID-19 and is predicted to continue to do so.

Data examining the current and future workforce showed that the national figures for the total radiology and radiography workforce are small relative to other health professional groups. In West Yorkshire, 265 radiologists and 926 radiographers were employed, and staff turnover was generally low. Trusts' forecasts for the number of radiologists and radiographers they believe they need suggest a 16% increase in the number of radiologists in post between March 2022 and March 2027 and a 25% increase in the number of radiographers in post. The numbers of radiographers and radiologists being trained in West Yorkshire suggest that this is feasible.

Interview data identified a number of main themes and associated issues: delivering diagnostic cancer targets, strategic workforce planning, workforce roles and skills, service transformation, recruitment and retention, universities, artificial intelligence, collaboration, and international recruitment. Across all themes, some reoccurring issues were identified: a lack of staff, increased demands, a lack of capacity in terms of space and staff, a lack of strategic workforce planning with a focus on operational or financial plans. Respondents proposed potential solutions to some of the issues raised that included: new ways of working, upskilling, developing current and emerging roles, Community Diagnostic Centres (CDCs), greater collaboration between NHS Trusts, universities, CDCs, imaging academies and networks and the private sector, and the international recruitment of radiologists and radiographers to address workforce gaps.

The rapid review findings helped to identify a number of potential benefits of use of AI in radiology, including contributing to improved workflow efficacy and efficiency of radiology services. However, this is dependent on the nature of the work and the AI function. As a result of faster AI reading, radiologists may be able to focus more on high-risk, complex reading tasks. AI can support automation of image segmentation and classification and aid the diagnostic confidence of less experienced radiologists. Respondents' views on AI were mixed. There was acknowledgement that AI was already used to support radiology service delivery and both the benefits and problems associated were identified. The implications of AI for radiologists' and radiographers' roles were discussed in terms of changing work, AI being used to support or in some cases substitute radiologists and radiographers, and the need for the radiology workforce to adapt to the technological change whilst maintaining a caring service.

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1. Introduction

The publication of the Delivery plan for tackling the COVID-10 backlog of elective care (NHSE/I, 2022:5) identified a number of ambitions, including that, by March 2024, 75% of patients who have been urgently referred by their GP for suspected cancer are diagnosed or have cancer ruled out within 28 days. Equally, by March 2025, waits of longer than a year for elective care should be eliminated and 95% of patients needing a diagnostic test should receive it within six weeks. The report (NHSE/I, 2022:27) acknowledged the need to grow the workforce to achieve these ambitions and ensure a timely cancer diagnosis, while also proposing the use of digital technology and data systems to free up capacity.

To assist West Yorkshire NHS Organisations to meet these ambitions, this report presents the findings of a 'deep dive' into the cancer diagnostics workforce, focusing on the radiologist and radiographer workforce in West Yorkshire. Briefly, radiologists are doctors who perform interventional procedures and interpret imaging tests, whilst radiographers are technical specialists who deliver and facilitate many radiological procedures, such as operating scanning equipment.

1.1 Aims

1. To understand current and projected demand for radiology expertise in cancer diagnosis in West Yorkshire.
2. To understand the current and projected radiology workforce in West Yorkshire and determine the gap between the projected radiology workforce and the required radiology workforce.
3. To identify possible solutions to assist in providing the radiology workforce required for West Yorkshire and explore their acceptability and potential impact.

1.2 Context of Radiology services

A series of policy documents and changes have influenced radiology services and the radiology and radiography workforce and will be briefly discussed. Both the Cancer Workforce Plan (HEE, 2017) and HEE's Strategic Framework for cancer workforce (HEE,2018) proposed measures to increase the workforce, upskill staff and introduce new ways of working. The perennial issues have been the increase in demand for radiology services, lack of capacity, and workforce problems due to insufficient staff and recruitment and retention issues. Following the publication of the NHS Long Term Plan (NHS England, 2019), Professor Sir Mike Richards was commissioned to undertake a review of the NHS diagnostics capacity and issued an independent report, Diagnostics: Recovery and Renewal (NHS England, 2020). This report outlined the constraints facing the NHS for imaging and noted that prior to the pandemic, the need for a radical improvement in diagnostic services was identified due to the increased demand experienced over the previous five years, increased in-patient hospital attendances, more requests for tests from GPs, and greater use of technologies, such as CT scanning (NHS England, 2020:6). The increased demand for diagnostic services led to breaches of the six-week diagnostic standard and resulted in the need to outsource some imaging (including reporting). There was agreement that without investment and reform in equipment, facilities, and the workforce, waiting time standards were likely to decline. Additionally, the achievement of several NHS Long Term Plan targets, including the ambition to diagnose 75% of people with cancer at an early stage, would be jeopardised, efficiencies not achieved and improvements in patient outcomes threatened (NHS England, 2020:8).

The Richards' Review (NHS England, 2020:8) noted these issues had been exacerbated by the COVID-19 pandemic and the backlog of patients waiting more than six weeks for diagnostics had increased significantly. To address these issues, the Richards' Review (NHS England, 2020:8) proposed a series of recommendations and a major expansion and reform of diagnostic services over the next five years to facilitate the recovery from the pandemic and meet rising diagnostic demand. It identified a need for new facilities and equipment, together with a significant increase in the diagnostic workforce, skill-mix initiatives, and the establishment of new roles working across traditional boundaries. The Richards' Review (2020:35) noted:

> A wide range of health professionals is needed to provide a high quality, efficient diagnostic workforce. However, over recent years expansion of these professional groups has not kept pace with increases in demand and activity. As demand continues to rise over coming years it will be vital to increase recruitment and training in all these groups.

Some of the key recommendations for radiology services were: the creation of new care pathways to streamline diagnosis and to separate emergency and elective patients, new Community Diagnostic Centres (CDCs), a doubling of CT scanner capacity, an increase in training places for radiologists and radiographers, an increase in advanced practitioner radiographer roles, imaging networks, and clarity around the regulatory landscape for imaging AI (NHS England,2020:5-6).

In terms of radiology workforce increases over the next five years, it was proposed that 2,000 more radiologists were required, 500 advanced practitioners/reporting radiographers and 3,500 radiographers (NHS England, 2000:37). However, the annual clinical radiology census by the Royal College of Radiologists (2022:3) stated, 'Our 2021 census reveals an increasingly worrying picture of staff shortages, leading to increasing workforce pressures impacting on patient safety and quality of patient care, resulting in reduced staff retention'.

The House of Commons Committee of Public Accounts (2022) report NHS backlogs and waiting times in England highlighted similar concerns to the Richards' Review and notes, 'in December 2021, only 67% of patients with an urgent referral for suspected cancer were treated within 62 days compared with a requirement for 85% to be treated within that time' (Committee of Public Accounts, 2022:3). The report further outlines the declines in waiting time performance for cancer care since 2014 and elective care from 2016, with no increase in capacity sufficient to meet the growing demand for NHS services (Committee of Public Accounts, 2022:3). Furthermore, they concluded the NHS will be less able to deal with backlogs if it does not address longstanding workforce issues and ensure the existing workforce, including in urgent and emergency care and general practice, is well supported (Committee of Public Accounts, 2022:5).

The national challenges facing radiology services were summarised in Transforming elective care services in radiology (NHSE/I, 2019a:6-7) and included the high demand for imaging services, a national shortage of radiologists and radiographers, delays due to quality and length of time for reporting, unwarranted variation in service provision, and the pace of advancement in technology.

In February 2022, the Delivery Plan for tackling COVID -19 backlog of elective care was published and noted that, although the NHS had continued to prioritise cancer treatment throughout the pandemic, it had seen record levels of urgent suspected cancer referrals since March 2021 (NHSE/I, 22:5). To address the problems identified, several ambitions for delivering cancer diagnostics were issued. To assist delivery of the ambitions, four areas were identified: increasing health service capacity, prioritising diagnosis and treatment, transforming the provision of elective care, and providing better information and support to patients (NHSE/I, 2022: 7). The ambition for the workforce was summarised as a need to 'more systematically train, recruit and retain staff,' as well as create 'more opportunities for current staff and those returning to practice working flexibly and remotely, and to develop new skills to progress in their careers' (NHSE/I, 2022:14). The actions proposed to deliver these ambitions included: better alignment of financial and workforce planning, an increase in the permanent workforce capacity, international recruitment, recruitment of 5,000 healthcare support workers, expansion of staff banks, the introduction of new roles, greater use of AI, imaging software to free up imaging staff time, more staff working flexibly across services, and more cancer pathway navigators to help patients move between services (NHSE/I, 2022:15). The report also noted (NHSE/I, 2022:18) the need to ensure all clinical roles spend more time treating patients and that greater use of digital technology, together with new technologies based on AI and automation, would assist this. In addition, new organisational structures and systems intended to help with delivering timely cancer diagnostics were introduced.

The creation of CDCs was recommended in the Richards' Review Diagnostics: Recovery and Renewal. The proposal was that NHS organisations across England move to providing diagnostic services in CDCs as this allows patients to access planned diagnostic care nearer to home (HEE, 2022a). To meet the government's aim of transforming diagnostics and making patient testing faster and more convenient, the Delivery Plan for tackling COVID -19 backlog of elective care included an increase in diagnostic capacity and CDCs (NHSE/I, 2022:31). The CDCs are part of the overall aim to separate urgent and elective care, by taking patients requiring diagnostic services out of the acute sector. Potentially, CDCs will deliver 'bundles of tests in a single appointment' and enable faster diagnosis of cancer and other conditions (NHSE/I, 2022:32). An increase in digital technology is anticipated to support this by speeding up test turnaround times and digital sharing of results. Different models of CDCs have been proposed. While Standard CDCs will deliver nationally-set minimum diagnostic tests and any other tests deemed a priority locally, Large CDCs will deliver the above but must additionally offer endoscopy and any other tests deemed a priority locally. The Hub & Spoke model within which CDCs will be based? will feature a central hub delivering nationally-set minimum diagnostic tests with spokes providing additional capacity to the hub *via* satellite location or mobile or pop-up units (see Community Diagnostic Hubs).

The NHS Long Term Plan also included recommendations for the establishment of Imaging Networks across England by 2023 and noted they are part of broader reforms in the way diagnostic services are organised. This means test results can be turned around quickly and staff time and skills used more effectively. In November 2019, Transforming imaging services in England: a national strategy for imaging networks (NHSE/I, 2019b:4-5) set out plans regarding how this would be achieved. Anticipated benefits include improved sustainability and service resilience, staffing consistency and flexibility, staff retention through flexible working and flexible retirement opportunities, economies of scale in procurement for both capital equipment and outsourcing, reducing unwarranted financial variation of both pay and non-pay costs, ensuring equal access for all patients irrespective of geography, shared capacity and management of imaging reporting backlogs to optimise reporting turnaround times, maintaining high quality learning and training environments, and a cohesive approach to quality improvement across imaging networks (NHSE/I 2019b:4-5). The Diagnostic Imaging Network Implementation Guide (NHSE/I, 2021) provided further guidance, noting the essential role of Imagining Network scan play in developing comprehensive workforce plans that cover: skill mix, insourcing, training and Continuing Professional Development (CPD), recruitment and retention and staff mobility within the network (NHSE/I,2021:10). To assist with this, Imaging

Academies are anticipated to provide multi-professional environments where training and education of the future imaging workforce is the primary focus (HEE, 2022b).

Some of the challenges facing radiology services were also outlined in a report by the Royal College of Radiologists (RCR) (2021: 4) Policy Priorities for Clinical Radiology 2021-2026. The report noted that demand continuing to outweigh capacity had led to increased costs for the NHS due to delayed diagnosis and outsourcing work. The measures the RCR proposed were: an investment in the workforce, an increase in training capacity, facilitating skill mix, enabling overseas recruitment, and enhancing the working environment. Initiatives such as CDCs, rapid diagnostic centres, integrated imaging networks, AI and digital technologies were seen as, 'effective methods of streamlining pathways and maximising the workforce' (Royal College of Radiologists 2021: 4). However, they cautioned that the efficacy of these measures relies on equipment, a robust and well-resourced information technology infrastructure, and sufficient staff, both clinical and non-clinical.

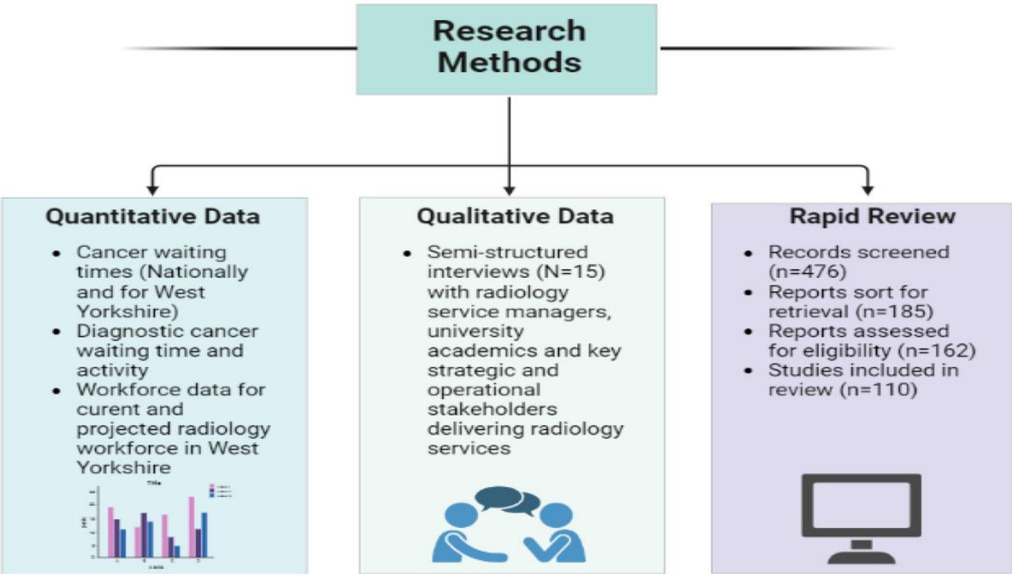
Another approach to achieving diagnostic cancer targets is the North West Imaging Workforce Strategy framework developed in North West England (Holroyd et al., 2020:7). The purpose of this was described as, 'to bring together current thinking and best practice to ensure a sustainable, skilled, healthy, flexible, and productive imaging workforce with the capacity and capability to meet the current and future demand for imaging services' (Holroyd et al., 2020:7). The framework provides actions and is a five-year workforce strategy that has been aligned with the HEE STAR model, focusing on leadership and management, ways to increase supply and bridge the gap, upskilling current staff, new roles, and new ways of working. The framework covers the roles of radiologists, diagnostic radiographers and sonographers, assistant practitioner radiographers and radiology support workers. For example, in relation to increasing the supply of assistant practitioner radiographers, one action is '*Maximise the use of the current AP workforce, ensuring that they are working at the top of their licence and consider expanding their scope of practice e.g., mobile and theatre imaging, DEXA and nuclear medicine'* (Holroyd et al., 2020:17).

This brief review of the factors affecting radiology services highlights the ongoing demand for radiology, the backlog of patients waiting for diagnostic tests, and workforce shortages, together with some proposed measures to address the issues. Consequently, understanding the current and future radiology workforce in West Yorkshire is pivotal to delivering cancer diagnosis services.

2. Methods

A variety of different methods were employed to gather the data for this deep dive. These are shown in Figure 1 below.

Figure 1: Research methods



2.1 Cancer waiting times and diagnostic waiting times and activity data

Publicly available data from NHS England on cancer waiting times and diagnostic waiting times and activity were used. To analyse these data, we used the R 'Prophet' package which is an open-source library for univariate time series forecasting. Prophet implements an additive time series forecasting model where non-linear trends are fit with yearly, monthly, weekly, and daily seasonality. More detail about the forecasting approach used is available in Taylor and Letham (2017).

For cancer waiting times data, we used monthly proportion of cancer patients who received their first treatment within one month as a time series variable for national and West Yorkshire trends and seasonable variation. We further forecasted a 24-month trend.

For diagnostic waiting times and activity data, we used monthly total activity or the total number of people waiting as a time series variable for national and West Yorkshire trends and seasonable variation. We further forecasted a 24-month trend. Regional activity was determined by combining the data for the five acute NHS Trusts of West Yorkshire (Airedale NHS Foundation Trust; Bradford Teaching Hospitals NHS Foundation Trust; Calderdale, and Huddersfield NHS Foundation Trust; Leeds Teaching Hospitals NHS Trust; and Mid Yorkshire NHS Trust). Definitions for the diagnostic test waiting time and activity data are presented in Diagnostic waiting times and activity, Guidance on completing the “diagnostic waiting times & waiting” monthly data collection (2015/2006).

2.2 Workforce data

The workforce data consisted of information gathered from NHS Digital national workforce datasets and the HEE eProduct Portal and data submitted by West Yorkshire acute Trusts to HEE for multi-year workforce modelling. The following data were included:

- National workforce data for all radiologists and radiographers
- West Yorkshire workforce profile data by headcount for radiologists and radiographers for age and gender
- West Yorkshire workforce profile data for radiologists and radiographers by Trust
- Number of radiologists completing training within West Yorkshire
- Number of radiographers graduating within West Yorkshire
- Planned establishment of radiologists and radiographers over the next 5 years across the West Yorkshire acute Trusts.

2.3 Interviews

Semi-structured interviews (N=15) were conducted with radiology service managers, university academics and key strategic and operational stakeholders delivering radiology services. Prior to commencing the study, the researchers applied for ethical approval from the University of Bradford's Humanities, Social and Health Sciences Research Ethics Panel (HSHS). This was granted by the Chair of HSHS (ref: EC27051) in May 2022. In terms of the primary data, the researchers ensured the anonymity of the participants was assured and that all data collected were held in a secure facility.

Initially a radiology service manager was identified as a contact point and to assist the researchers in accessing other radiology service managers across West Yorkshire. The researchers sent information to the contact explaining the aim of the deep dive, the purpose of the interviews and other details in a participant information leaflet (Appendix 1). This information was emailed by the contact to other radiology service managers working across West Yorkshire Trusts. Respondents interested in participating were asked to email the researchers who then contacted the individual to organise an interview time and date that was convenient for them. Key strategic and operational stakeholders were either recommended by other participants or identified by their role as delivering radiology services. They were sent an introductory email explaining the research and a participant information leaflet. Respondents were asked to contact the researchers if they wanted to be involved and all those invited agreed to participate. The same process was followed to recruit university academics, with an initial request for participants sent out *via* Yorkshire Universities.

Prior to the interviews, an interview topic guide was developed (Appendix 2). Interview questions for radiology managers were organised into key themes: general information, strategic workforce planning, workforce changes and transformation workforce roles. Similarly, academics were asked some general questions about programmes and student numbers, before exploring strategic workforce planning and the implications for universities, workforce roles, education, service changes and transformations, and the role of artificial intelligence in radiology services. All participants were offered the opportunity to include any other comments if they wished.

Interviews were conducted online using Microsoft Teams, digitally recorded [with participants' permission] and ranged in length from sixty to ninety minutes, with an average of seventy minutes. Prior to commencing the interviews participants were reminded of the aim of the study and assured of their confidentiality and anonymity.

Once the interviews were completed, the recordings were transcribed verbatim and thematic analysis used to analyse the material and identify the key themes and issues (Braun and Clarke, 2006, Silverman, 2013). Thematic analysis is the clustering of concepts and meanings within the data into groupings or themes (King et al. 2019). This involved the text/sentence within each transcript being assigned line numbers so that any extracted issues could be traced to the source. The researchers read the transcript and checked this against the recording for accuracy. Individual transcripts were scrutinised for issues, and these were extracted, with quotes, and inserted into tables in Microsoft Word that comprised themes, codes, and issues. The themes and issues were constantly reviewed and revised for accuracy. To provide an additional, more objective perspective, another researcher also listened to some of the tapes and independently reviewed two transcripts which the research team discussed to ensure the relevancy of the themes and issues. The decision not to use software such as NVivo that supports qualitative and mixed methods research was based on the research team's view that analysing and organising the material would familiarise them with the content and assist with the revision and finalisation of themes and issues.

2.4 Rapid review

A rapid review facilitates a synthesis of a range of primary research literature and relevant policy documents within a short timeframe. Such reviews are noted as accelerated means of drawing together evidence to aid decision-making in healthcare settings (Tricco et al. 2015; Kelly et al. 2016). Guidance from the Cochrane Rapid Reviews Methods Group (Garrity et al. 2021) was used to structure the protocol of the rapid review. Once the protocol was agreed between the review team it was lodged with the International Prospective Register of Systematic Reviews (PROSPERO) and is identifiable by: CRD42022341257.

In summary, the rapid review involved searching the following five databases: arXiv, Cochrane Library, Embase, Medline and Scopus with variations of the following search string used in Embase, Medline and Scopus: "radiolog*" AND ("artificial intelligence" OR "machine learning" OR "deep learning" OR "image analysis") AND ("workload" OR "skill mix" OR "productivity"). Searches were limited by English language literature published between January 2007 and May 2022. A Health Studies Subject Librarian provided expert guidance regarding literature searching.

The flowchart for full text screening, which was developed from the initial title/abstract screening algorithm, is presented in Appendix 3. The Mixed Methods Appraisal Tool, Version 2018 (Hong et al. 2018) was used to evaluate the quality of included items (Appendix 4). A thematic analysis and narrative synthesis of key findings was then conducted. Appendix 5 is a summary of included literature following full text screening.

Sections 3, 4 and 5 of this report summarise findings derived from the data collection methods outlined above. First, section 3 reviews current and projected demand for radiology services (Aim 1 of the research), drawing on cancer waiting times and diagnostic waiting times and activity data, then section 4 explores the current and projected radiology workforce (Aim 2), based on workforce and interview data. Finally, section 5 considers possible solutions to address gaps in the required and projected radiology workforce (Aim 3), derived from interview data.

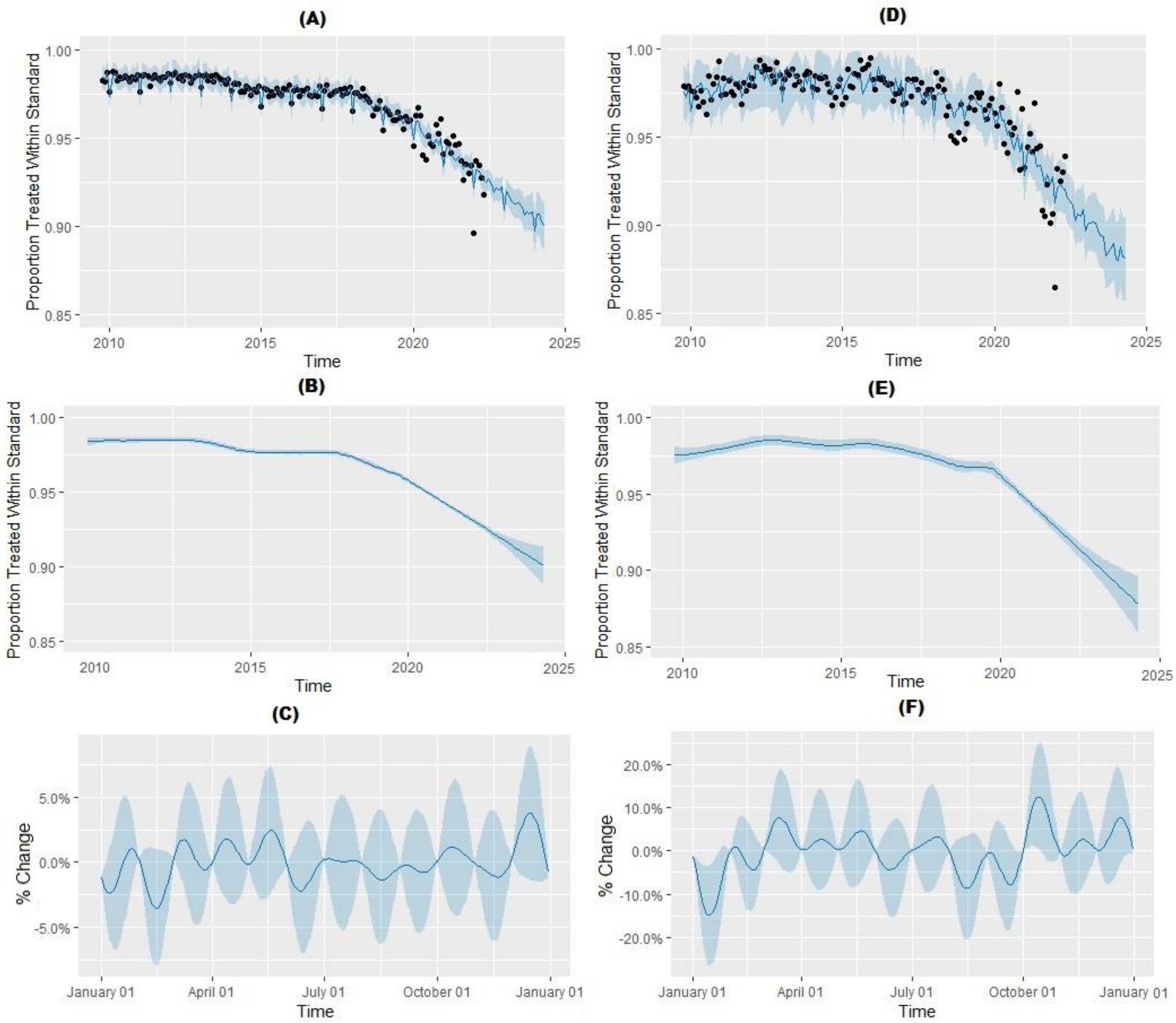
3. What is the current and projected demand for radiology services? Findings from cancer waiting times and diagnostic waiting times and activity data

There is a growing backlog of care across the NHS in the United Kingdom. The House of Commons Committee of Public Accounts (2022: 3) noted, 'At the end of December 2021, 6.07 million patients were waiting for elective care, the biggest waiting list since records began.' The British Medical Association NHS backlog data analysis (2022) similarly notes concern, particularly in relation to missed cancer targets and comments that, 'the 93% target for patients to be seen within that time frame has not been met since May 2020'. As discussed, the backlog of care and ambitions set are addressed in the Delivery plan for tackling the COVID-19 backlog of elective care (NHSE/I, 2022).

3.1 Cancer waiting times

Radiologists and radiographers play a critical role in the diagnosis of cancer and therefore, to understand the demand for radiology services, we began by looking at cancer waiting times. Figures 2 (A) and (D) show that the proportion of people treated within accepted waiting times decreased nationally and within the West Yorkshire region. The proportion of patients who experienced waiting times within these limits first declined around 2013 nationally (see Figure 2 (A)) and COVID-19 caused a further decrease nationally and for the West Yorkshire region. Figures 2 (B) and (E) show a downward trend, with COVID-19 accelerating this decline. The percentage change in the proportion of people treated within a standard time has a minimal cyclical variation (% Change) (see Figures 2 (C) and (F)).

Figure 2: Trend and forecasting of the proportion of people treated (received 1st treatment) within standard time (one month) with 95% Confidence Intervals (CIs)



Nationally (Left) **(A)** Forecasting **(B)** Trend only **(C)** Cyclical variation only and for West Yorkshire region (Right) **(D)** Forecasting **(E)** Trend only **(F)** Cyclical variation only **Note:** Black solid dots are shown observed activity data whereas the blue line plot represents the predicted trend along with the blue shaded 95% confidence interval. The proportion of patient treated within standard (on y-axis) is fixed between 0.85 and 1.00 for national and regional trend and forecasting.

3.2 Diagnostic Waiting Times and Activity

While the cancer waiting times data show that patient needs are not being met and that this is likely to worsen, what we do not know is to what extent such outcomes are due to delays within radiology services. Therefore, we looked at diagnostic waiting times and activity data, as current and future trends in waiting times for diagnostics may act as indicators of national and regional demand for radiology services. We began by looking at the national data for all diagnostic tests (Figures 3 and 4).

Figure 3: Percentage waiting times for 6+ and 13+ weeks – National

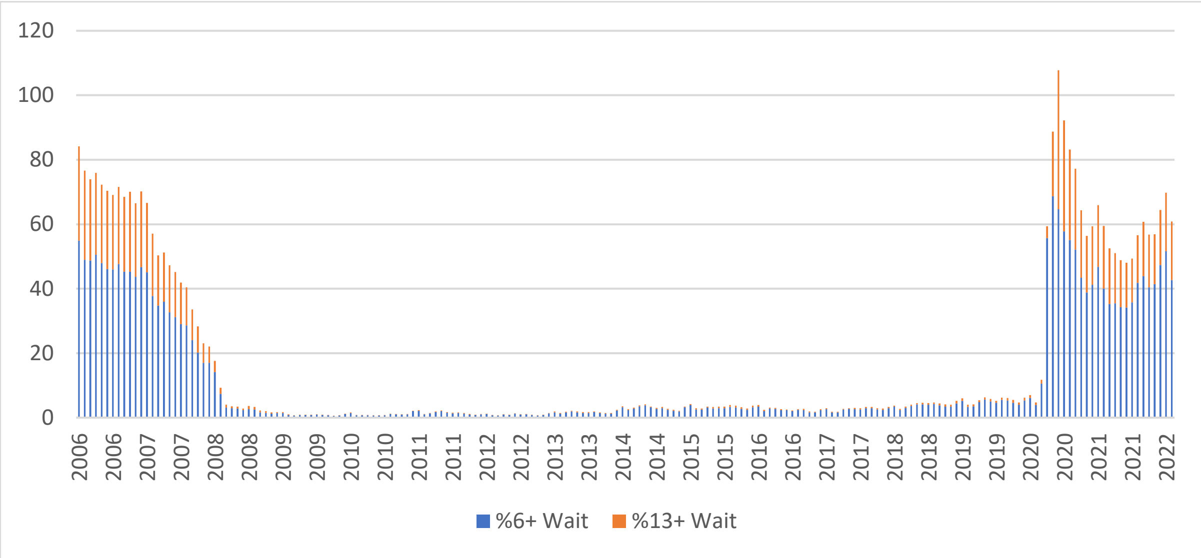


Figure 4: Median (number of weeks) waiting time – National

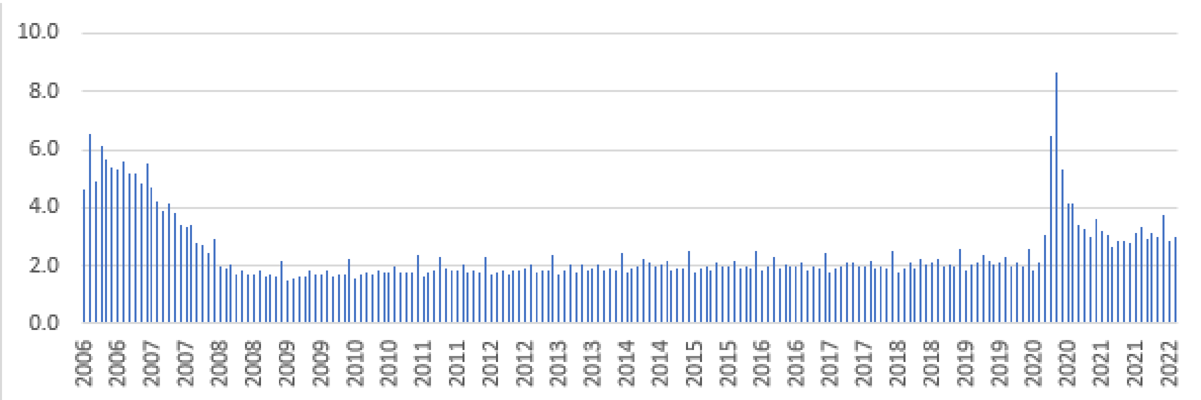


Figure 4 shows a noticeable decline in waiting times for diagnostics between 2006 and 2008 with a decrease in median waiting times from just under 6.0 weeks to approximately 2.0 weeks in 2008. Median waiting times then remained stable at around 2.0 weeks until later in 2020. The longest median waiting times of just over 8.0 weeks was in mid-2020.

To better understand these trends and the potential role of radiology services, we broke the data down. Fifteen named diagnostic tests/procedures, which are organised into three sub-groups, are presented within the diagnostic waiting times and activity data. The three sub-groups are: imaging, physiological measurement, and endoscopy. Imaging diagnostics includes Magnetic Resonance Imaging (MRI); Computer Tomography (CT); Non-obstetric Ultrasound; Barium Enema (BE) and DEXA Scan (DS). We chose these diagnostic tests as best-fit illustrations of radiology services' activity. National data for named radiology and other tests are presented in Figures 5 to 7 and reflect a similar pattern to that for all diagnostic tests.

Figure 5: Percentage 6+ weeks waiting time for named radiology and other tests – National

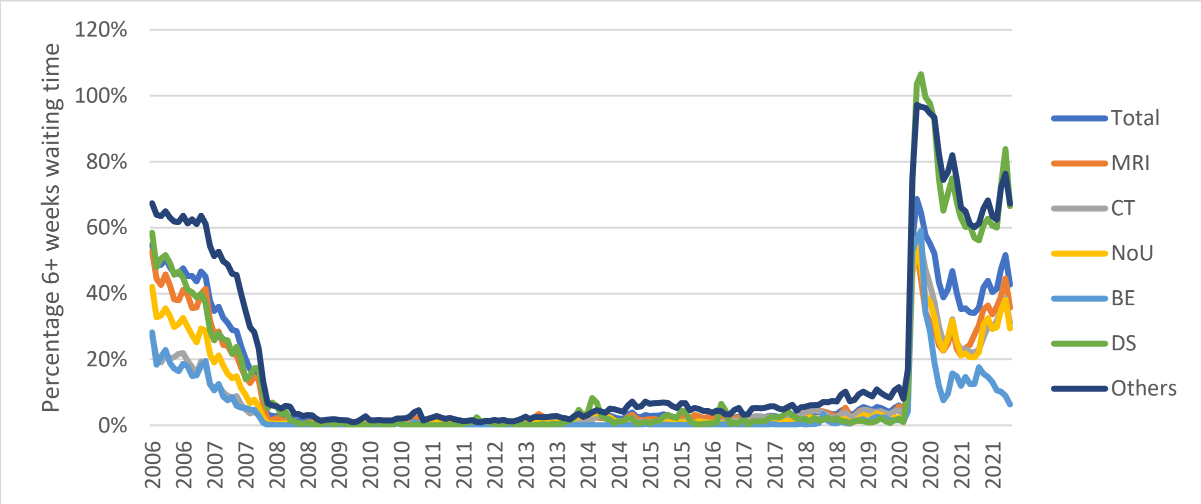


Figure 6: Percentage 13+ weeks waiting time for named radiology and other tests – National

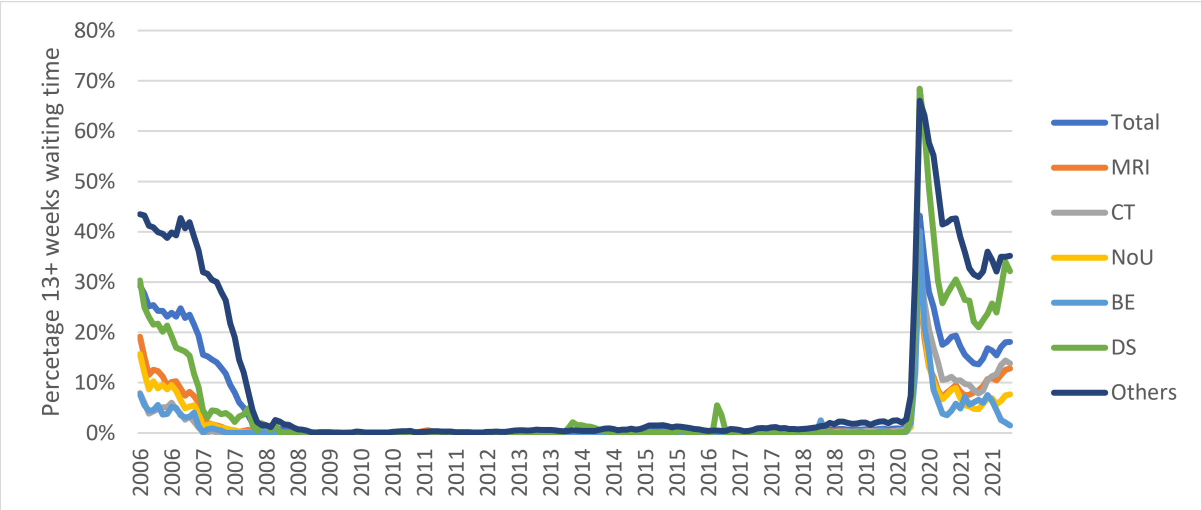
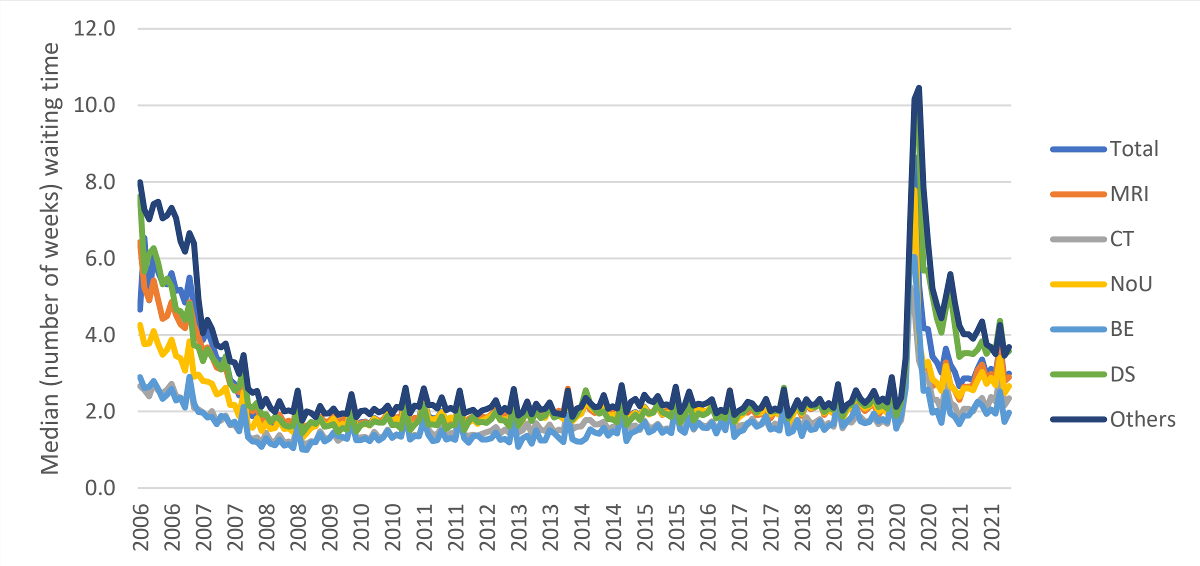
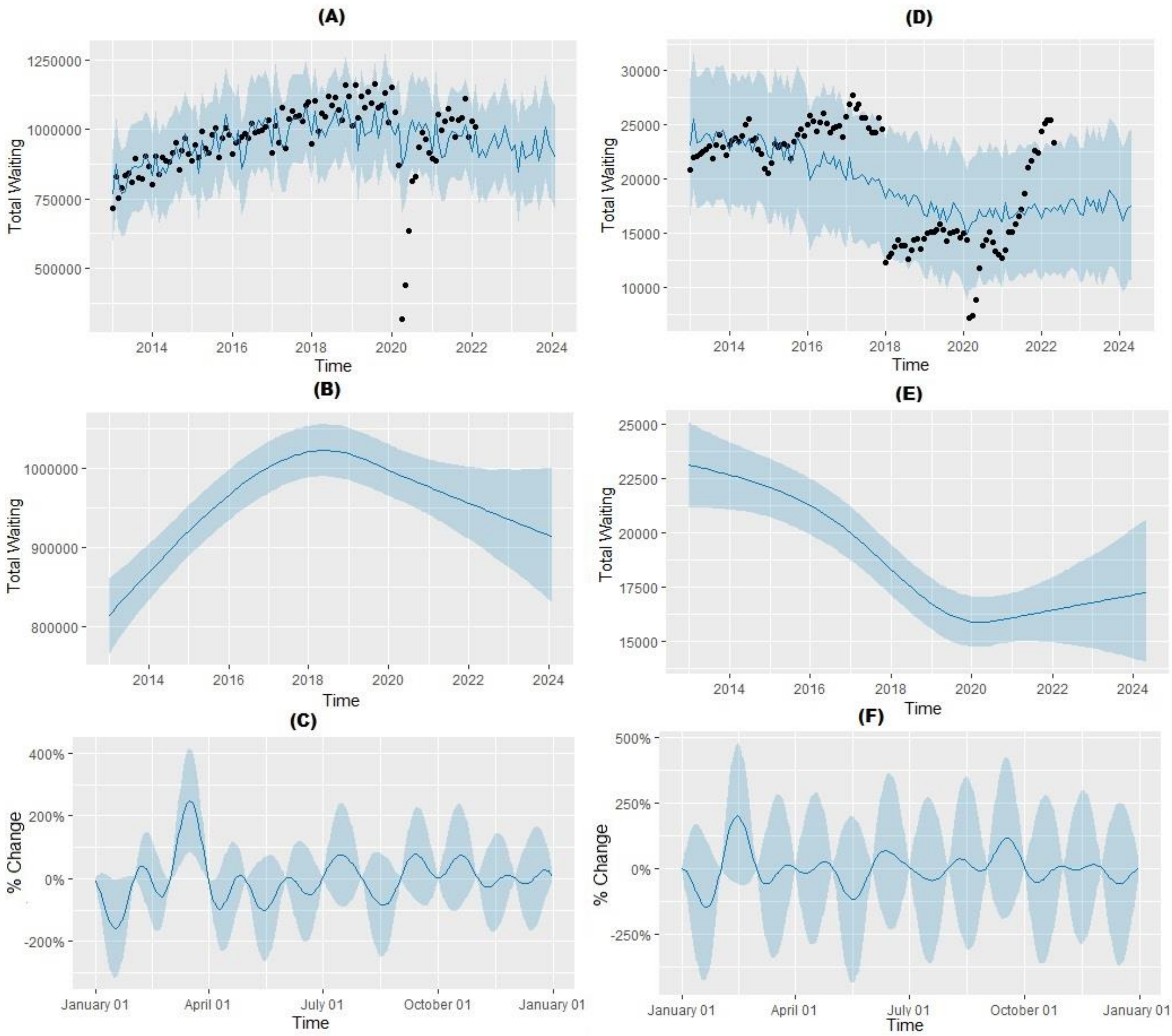


Figure 7: Median (number of weeks) waiting time for radiology tests – National



Figures 8 (B) and (E) below show the total number of people waiting for radiology tests nationally is decreasing and is predicted to continue to do so, while in West Yorkshire the number of people waiting for radiology tests decreased until 2020 but has since been on an upward trend which is predicted to continue.

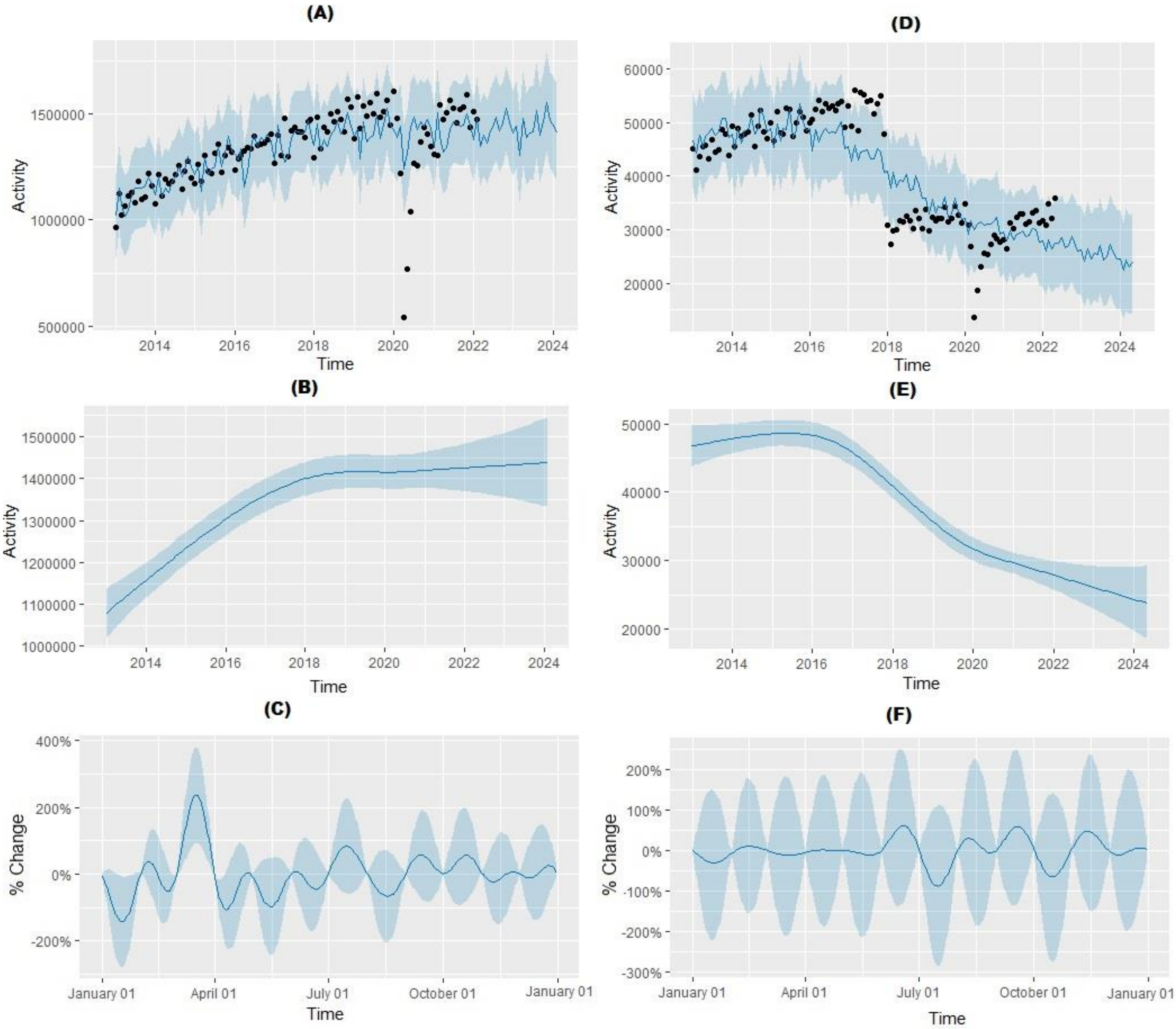
Figure 8*:* Trend and forecasting of the total number of people waiting for imaging with 95% Confidence Intervals (CIs)



Nationally (Left) **(A)** Forecasting **(B)** Trend only **(C)** Cyclical variation only and for West Yorkshire region (Right) **(D)** Forecasting **(E)** Trend only **(F)** Cyclical variation only **Note:** Black solid dots are shown observed activity data whereas the blue line plot represents the predicted trend along with the blue shaded 95% confidence interval.

Finally, we looked at national and regional data for activity for radiology tests. Figures 9 (B) & (E) show a national increase in activity whereas within West Yorkshire activity has been decreasing since well before COVID-19 and is predicted to continue to do so.

Figure 9: Trend and forecasting of total imaging activity with 95% Confidence Intervals (CIs)



Nationally (Left) **(A)** Forecasting **(B)** Trend only **(C)** Cyclical variation only and for West Yorkshire region (Right) **(D)** Forecasting **(E)** Trend only **(F)** Cyclical variation only **Note:** Black solid dots are shown observed activity data whereas the blue line plot represents the predicted trend along with the blue shaded 95% confidence interval.

3.3 Summary

Overall, the findings show that demand for radiology services is increasing and that both cancer waiting times and the waiting times for diagnostic tests increased, with a concurrent downward trend in activity that is predicted to continue up to 2025. The cancer waiting times data indicate that patients were waiting longer and that their needs were not being met. Moreover, the proportion of people treated within expected cancer waiting times decreased both nationally and within the West Yorkshire region, from 2013. This was exacerbated by COVID-19 which caused a further decrease nationally and for the West Yorkshire region.

National data for waiting times for diagnostic tests show a significant decline between 2006 and 2008, with a decrease in median waiting times from just under 6.0 weeks to approximately 2.0 weeks. Overall, waiting times remained stable until late 2020 when they started to rise, with the longest median waiting times at just over 8.0 weeks in mid-2020. The findings for named diagnostic tests reflect the same trends. The total number of people waiting for radiology tests nationally is decreasing and is predicted to continue to do so, while in West Yorkshire the number of people waiting for radiology tests decreased until 2020 but has since been on an upward trend which is predicted to continue. Nationally, the total number of radiology tests is on an upward trend that is predicted to continue, while in West Yorkshire activity has been decreasing since well before COVID-19 and is predicted to continue to do so.

These findings suggest that, despite the targets set by NHS England and NHS Improvement (2022) in the Delivery plan for tackling the COVID-19 backlog of elective care, demand for radiology services in West Yorkshire continues to increase and will for the foreseeable future. An inability to meet cancer targets both nationally and in West Yorkshire had been an issue for some years prior to COVID-19, which heightened the demand and unmet needs of patients requiring healthcare, notably cancer care diagnostics. While, based on the data presented, it is not possible to predict the number of radiologists and radiographers required to meet demand, it does suggest that the current workforce is not sufficient and, if all else remains the same, the numbers required to meet demand will continue to increase.

4. What is the current and projected radiology workforce in West Yorkshire? Findings from workforce and interview data

To understand the current and projected radiology workforce for West Yorkshire we examined workforce data for radiologists and radiographers. Initially, national workforce data from NHS Digital was considered to gain an overview of the total radiology and radiography workforce in England. The total radiology and radiography workforce for West Yorkshire was then reviewed, followed by specific workforce data for each of the five West Yorkshire acute Trusts: Airedale NHS Foundation Trust (AFT), Bradford Teaching Hospitals NHS Foundation Trust (BTHFT), Calderdale and Huddersfield NHS Foundation Trust (CHFT), Leeds Teaching Hospitals NHS Trust (LTHT) and Mid Yorkshire Hospitals NHS Trust (MYHT). To understand the projected radiology workforce, we looked at Trusts' forecasts for the numbers of radiologists and radiographers they believe they will need in post over the next five years, before looking at the numbers of radiologists completing their training and the number of radiographers graduating, to understand the feasibility of these forecasts.

Table 1: National radiography workforce

Role	Oct- 20	Nov-20	Dec-20	Jan-21
Radiography (diagnostic) Total	15,608	15,639	15,622	15,612
Consultant Therapist / Scientist	103	105	104	103
Manager	489	496	499	503
Therapist	15,008	15,031	15,012	14,998
Tutor	8	7	7	7

Source https://digital.nhs.uk/data-and-information/publications/statistical/nhs-workforce-statistics/january-2021#highlights

Table 1 shows national data for the radiography workforce and illustrates a stable workforce of 15,612 (since 2019 the total workforce has been over 15,000) with the majority employed as therapists.

Table 2: National radiologist workforce

Specialty	Consultant	Associate Specialist	Specialty Doctor	Staff Grade	Specialty Registrar	Core Training	Foundation Doctor Year 2	Foundation Doctor Year	Total
Clinical radiology	3,364	31	55	6	1,299	51	7	5	4,819
Nuclear medicine	61	0	5	0	15	0	1	0	82
Total	3,425	31	60	6	1,314	51	8	5	4,901

Source: https://digital.nhs.uk/data-and-information/publications/statistical/nhs-workforce-statistics/january-2021#highlights

Table 2 is the radiology medical workforce in England by role in January 2021. A total of 4,819 clinical radiologists were employed, with the majority in consultant posts, supported by 1,299 specialist registrars. The data point to the seniority of the radiology workforce.

4.1 West Yorkshire workforce profile for radiologists and radiographers

The total headcount for radiologists in West Yorkshire is 265 employed at different grades. Figure 10 shows the consultant radiology workforce is 167. Trends for these staff in post from June 2021- June 2022 reveal some fluctuations, with an increase of 7 consultant posts across West Yorkshire. The average age of the consultants is 46 years, with 11.5% over the age of 56 years which may have implications for delivery of cancer targets, dependent on when the consultants are retiring.

Figure 10: Consultant radiologist workforce in West Yorkshire

Figure 11: Diagnostic radiography workforce in West Yorkshire

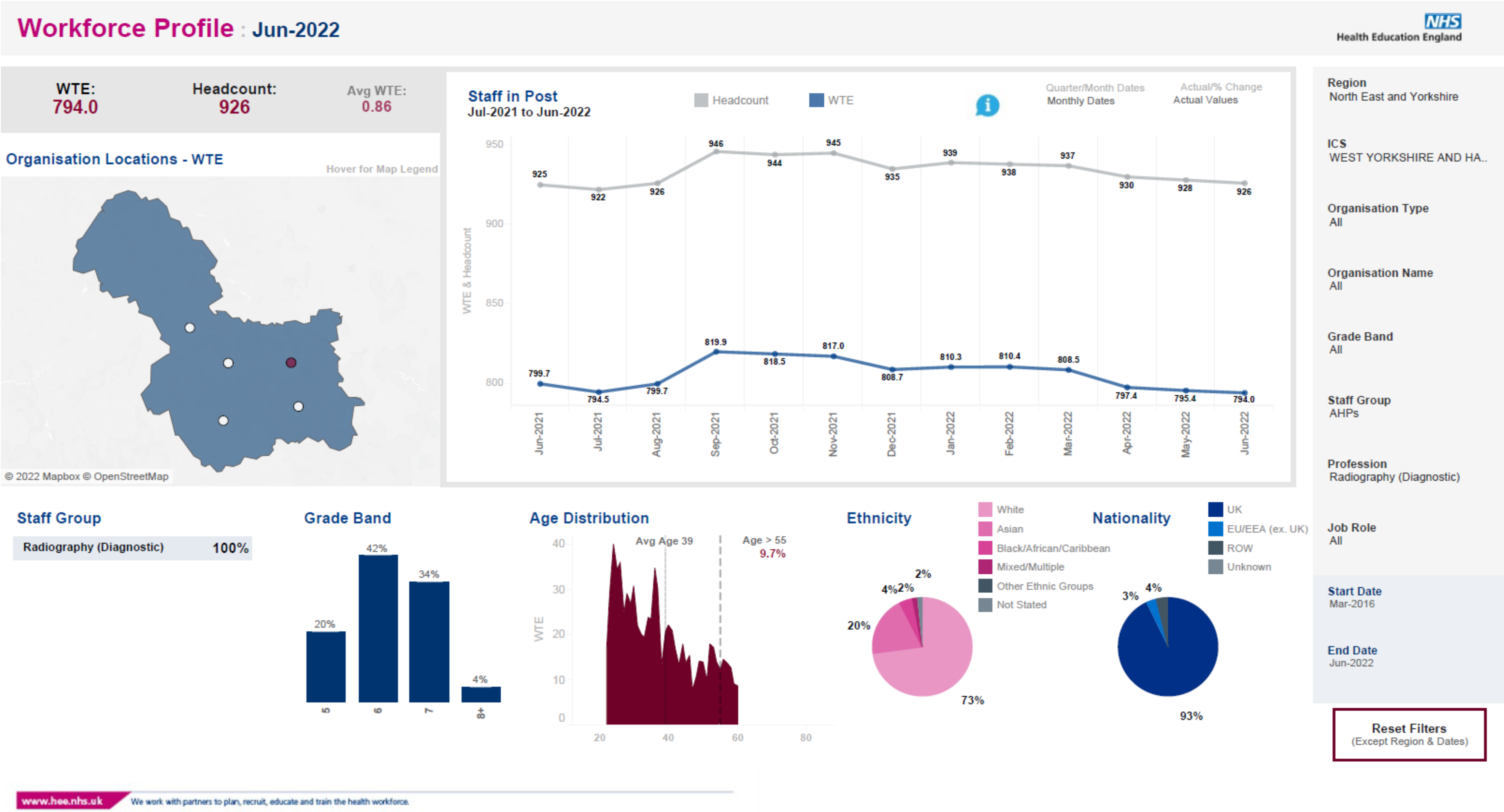


Figure 11 shows the diagnostic radiography workforce total head count for West Yorkshire is 926. Trends for staff in post from June 2021 to June 2022 indicate slight fluctuations in radiographers employed. Overall, workforce turnover is modest. The average age for radiographers is 39 years, with 9.7% of the population aged 55 years plus.

4.2 West Yorkshire workforce profile by Trust for radiologists and radiographers

The following data for clinical radiologists was compiled in January 2022, examining the age and gender of medical consultants and medical 'other', cover Airedale, Calderdale and Huddersfield, Bradford, Mid Yorks, and Leeds Trusts.

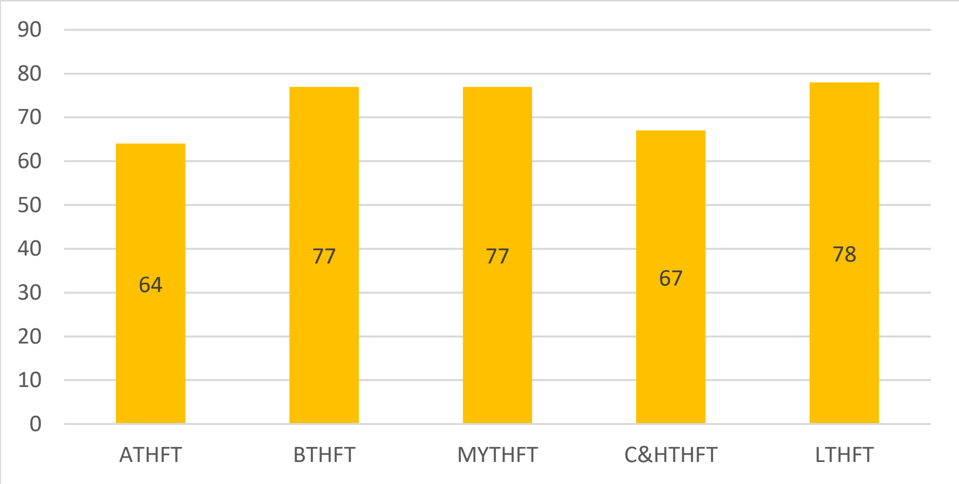
Overall, there is a consistent picture. Over 50% of radiology consultants are male (ranging from 56%-69% across all five Trusts). Age and gender data reveal some differences across the five Trusts and between different age groups. For example, there is a mixed picture at CHFT with 33%M/67%F in the 60s age band, and this variance is even more pronounced within younger age bands, e.g. the 30-34 age band is 100% female. MYHT is also varied, with equal male/female representation among the over-60s, whereas men tend to predominate in all other age bands. Similarly, at LTHT there was gender balance in the 55-60 age band, with slightly more uneven representation in some of the other age groups.

The data covering the diagnostic radiography workforce for the five West Yorkshire Trusts cover the variables age, gender, and agenda for change (AfC) grade bands. A noticeable difference was that the majority of the radiography workforce were women. This is consistent across all five Trusts, with over 76% of radiographers being women (proportions range from 76%- 88%). The predominance of women was found across all age groups for all five Trusts.

The next data set relates to the workforce profile for radiologists and radiographers for the five Trusts in detail from May 2021- April 2022 and includes headcount. In April 2022, the total headcount for the radiology workforce was 265. There was significant variation in the number of radiologists employed across the five Trusts, with AFT employing 10, BTHFT 27, CHFT 20, MYHT 36 and LTHT 170. Recruitment of radiologists over the period from May 2021-April 2022 was small, ranging from none to seven.

In April 2022, the total headcount for the radiography workforce was 926. The number of radiographers employed across the five Trusts was: AFT 56, BTHFT 135, CHFT 139, MYHT 200 and LTHT 403. Over the period March 2021-April 2022, the number of radiographers employed fluctuated more than radiologists, but was still relatively stable. The data show radiographer staff reduced in AFT by three, in CHFT by 13, in LTHT by three, while MYHT and BTHFT increased their radiographer numbers by seven and ten respectively. The average age distribution of the workforce across the five Trusts is 40 years. Data for grade bands (Figure 12) indicate that the radiographer workforce across all five Trusts is experienced and over 64% were employed at bands 6 and 7, with LTHFT employing 78% at these bands.

Figure 12: Radiographers employed at AfC bands 6 & 7 across the five Trusts



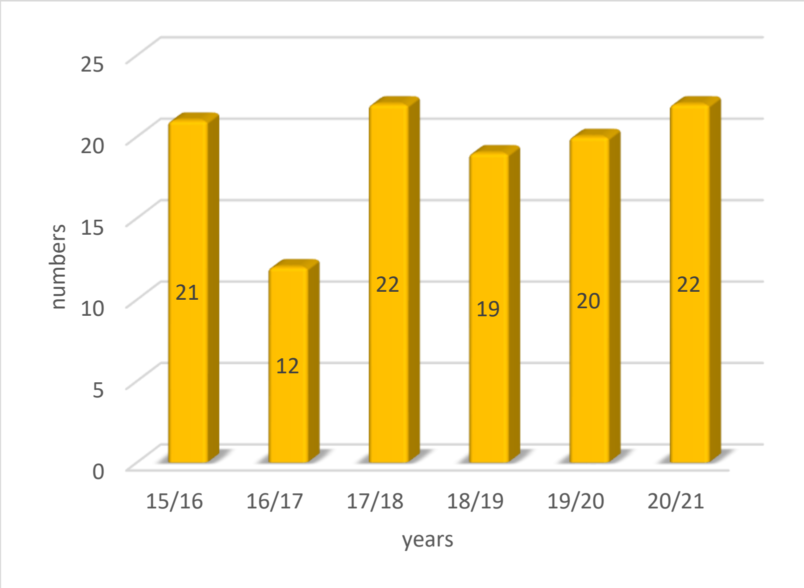
4.3 West Yorkshire projected workforce profile for radiologists and radiographers

As part of HEE's multi-year modelling data collection, West Yorkshire acute Trusts submitted their 5-year projections for radiologists and radiographers (see Table 3). It should be noted that HEE asked NHS organisations to be ambitious. However, it does reflect what the Trusts believe they need. The figures represent a 15.92% increase in the number of radiologists in post between March 2022 and March 2027 and a 24.95% increase in the number of radiographers in post.

Table 3: Projected radiologist and radiographer workforce for West Yorkshire

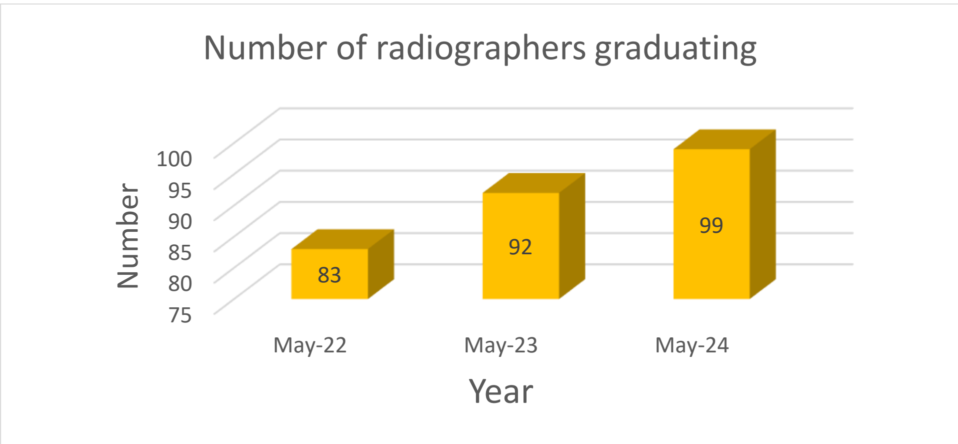
Staffing Categories			Forecast				
	Staff In Post	Establishment	Planned Establishment				
	31st Mar 2022	31st Mar 2022	31st Mar 2023	31st Mar 2024	31st Mar 2025	31st Mar 2026	31st Mar 2027
Clinical Radiology	**173.40**	**177.05**	**178.82**	**185.00**	**191.00**	**197.00**	**201.00**
Consultant	162.40	164.95	168.82	174.00	179.00	184.00	188.00
Non-Consultant Career Grades (excluding trainees)	11.00	12.10	10.00	11.00	12.00	13.00	13.00
Allied Health Professionals							
Radiography (Diagnostic)	815.94	886.72	886.60	936.78	967.48	988.48	1019.48

Figure 13: Radiologists completing training across Yorkshire and Humber



Trainee radiologists are experienced doctors who undertake a dedicated programme. Training is offered at three sites across Yorkshire - Leeds, Hull, and Sheffield - and radiology trainees rotate around their area. In April 2022, there were 159 (headcount) radiologist trainees in post across Yorkshire & the Humber, out of 172 available posts. Of the total, 76 (headcount) were placed in West Yorkshire Trusts during the rotation period. There were 26 new starters in Clinical Radiology across Yorkshire & the Humber in 2019 and 29 new starters in 2020. The number of radiologists completing their training over the last 6 years is shown in Figure 13. There are small numbers of radiologists due to qualify, which may be related to undertaking their programme part-time. However, the numbers do suggest that enough radiologists are being trained in West Yorkshire to enable Trusts to meet their ambitions in terms of employing greater numbers of radiologists.

Figure 14: Number of radiographers graduating



Diagnostic radiography is a three-year undergraduate degree course, delivered by two universities in West Yorkshire (University of Bradford and University of Leeds). The total number of students from 2018/2022 currently in training is 720. Figure 14 shows that the number of radiographers projected to graduate over the next three years is a total of 274, taking into account forecasted student attrition. On completion not all graduates will take up employment in West Yorkshire. However, the numbers do suggest that enough radiographers are being trained in West Yorkshire to enable Trusts to meet their ambitions in terms of employing greater numbers of radiologists.

4.4 Summary

The West Yorkshire workforce data can only be considered in broad trends but reveals that 265 radiologists and 926 radiographers are employed across the region and turnover is small. Gender distribution is specific to professions with the majority of consultant radiologists being male and most radiographers being women. This gender disparity persists through the different age groups, although in some Trusts it is more variable with evidence of greater gender proportionality.

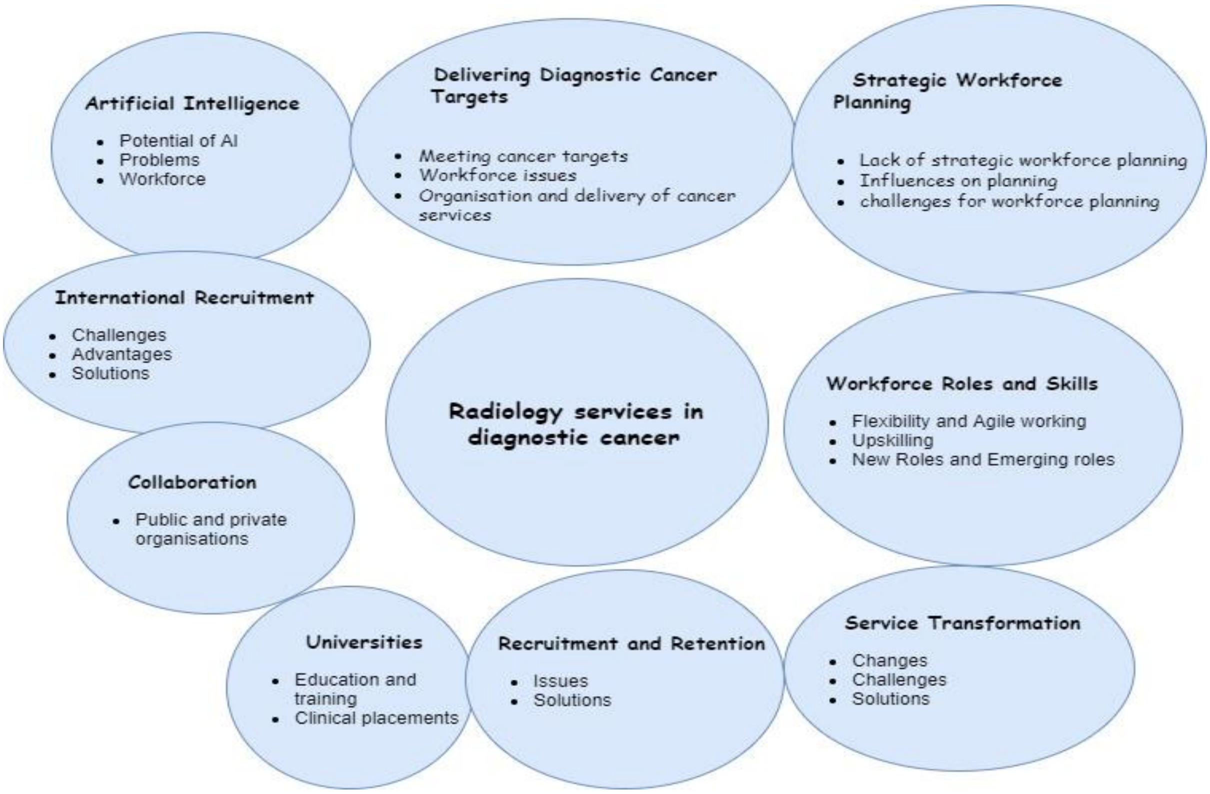
The data examining individual Trust's workforce in detail included headcount and shows the overall workforce is stable, with small numbers of radiologists and radiographer leaving and joining. Radiographers are experienced practitioners mainly employed at band 6/7 and so may be working as reporting radiographers.

The numbers of students/trainees are modest across West Yorkshire and in 20/21, 22 radiologists and 83 radiographers were expected to complete their training. However, this is enough for Trusts to be able to achieve their ambitions in terms of increased numbers of radiologists and radiographers. Findings from interviews with a range of NHS and university staff are explored in detail below, and suggest generally that radiologists are likely to stay in the area in which they trained, thereby replenishing the workforce, whereas for radiographers the picture is mixed, and they may be employed in areas outside of West Yorkshire.

4.5 Interview data

To complement quantitative data on the radiology and radiography workforce, we also undertook interviews (N=15) with radiology service managers, university academics and key strategic and operational stakeholders delivering radiology services. Figure 15 shows the nine themes and issues identified from thematic analysis. The discussion below presents the issues and includes quotations from interviewees in italics to illustrate them. Frequencies have been included for some issues to provide an indication of the number of responses. As the interviewees were not a homogenous population, a range of views have been captured and for some points the frequencies are small, but of interest. It is worth noting that there is a high degree of agreement between interviewees, irrespective of role or profession, on the themes and issues identified. Similarly, the themes and issues are interconnected and so reoccur, for example, delivering diagnostic cancer targets was reliant on strategic workforce planning, workforce roles and skills and service transformation. During their discussions, many interviewees proposed suggestions or solutions to the issues raised and these are presented in Section 5.

Figure 15 Themes from interview analysis



4.5.1 Delivering diagnostic cancer targets

While the quantitative data suggest that West Yorkshire will struggle to meet cancer targets with the current workforce, interview data provided respondents' perspectives on the targets. The key issues identified within this theme were: meeting cancer targets; workforce; and the organisation and delivery of cancer services and these are explored in more detail below.

4.5.1.1 Meeting cancer targets

The key issues discussed for meeting cancer targets were a perceived disconnect between strategic planning and the delivery of diagnostic services (N=12), the backlog of work (N=11), increased demand (N=10), a lack of staff (N=11) and insufficient capacity (N=4). According to interviewees, all these factors had been exacerbated by COVID-19. Some believed that the NHS had delegated achievement of the cancer plan to regional levels: *'the NHS needs to take it back under control so there's a planned strategy to get us to be able to achieve the cancer plan'***.** The problem of meeting cancer targets was described by an interviewee:

> *'Demand goes up every year in something like CT, which is where the cancer targets are going to hit most, demand goes up between 10% and 12% a year. So, if you think about the waiting lists there's thousands on those waiting lists'.*

Both radiologists and radiographers were aware of cancer targets and felt there was pressure to deliver on them (N=10). Although targets could be helpful, respondents believed they were often inaccurate or unrealistic: *'we struggled to meet them* [targets] *it's just always been this way and because it's always just been this way, it doesn't really matter if it's 2019 or whatever'*. Similarly, another commented, *'So the government can give all the targets they want, but actually I think in some ways Trusts are getting to the point of fail and let's have some intervention'.* Due to the pressure to deliver targets, managers [at all levels] were described as, *'hit by the big stick of just get through the numbers. Forever it's been that 'you must get through the numbers', that's what really counts.'* An example was given of the dilemma encountered between trying to meet cancer waiting time targets and financial targets, providing additional hours to cover service needs, using agency staff and the increased expense and attempting to balance these different factors.

Moreover, some interviewees suggested that medical/legal issues and a lack of confidence in clinical skills impacted on staff members' ability or willingness to make decisions based on clinical assessment. As a result, imaging was used in some circumstances unnecessarily to confirm or refute clinical diagnoses, further fuelling demand.

A collaborative working relationship between radiologists and radiographers was regarded as important and helped to meet targets. However, timescales for cancer targets were described as *'very tight'* (N=8) and, according to some, *'not achievable'* (N=6). It was suggested that factors such as higher cancer survival rates and more long-term follow-up screening were not always taken into account (N=4).

Although fast tracking patients was perceived as *'making a difference to cancer patients'* (N=4), targets meant that patients were not always prioritised on clinical need, but, rather, were based on other factors such as referral rates (N=3). Furthermore, targets could potentially disenfranchise areas if staff and funding were invested in a particular service at the expense of another.

Equally, some respondents felt that fast-tracking the patient's journey, while trying to manage patients' expectations and '*persuading them to travel between providers'* [which respondents pointed out as not being financially feasible for some patients] meant patients could feel as though they were, *'being pushed through the system and getting a diagnosis, but never having someone to talk it through [with]'.* Respondents highlighted the need to avoid a 'conveyor belt' system just to meet targets and the importance of continuing to provide a caring service. Measures cited to address these issues included triaging patients to prioritise them, improved cancer pathways to ensure the right patients were escalated for cancer diagnosis, clear clinical care pathways and evaluating these to establish the best way of meeting new diagnostic cancer targets.

Public expectations were described as 'high' and a respondent felt: '*We often find ourselves in radiology being blamed for somebody else's problem, "it's radiology's fault"***.** An example cited of the time taken for reporting illustrates the varied attitudes of different professionals to this subject. The interviewee explained, '*All A&E and urgent patients are seen first (3 days scan/report). If we have time, we look at others and there's a general feeling that's its pretty good. 40% found to have undiagnosed cancer. An alternative view is that a patient waiting 3 days in an NHS bed for diagnosis when we've got a bed crisis is "shocking*". Another interviewee observed that, compared to other countries, UK imaging waiting times were '*unacceptable': 'in most other countries, people expect the scan report either on the same day or within the next two days'.*

4.5.1.2 Workforce issues

The key workforce issues identified with delivering cancer targets were staff shortages (N=8), not being able to recruit enough staff (N=6), and insufficient radiographers reporting as they were too busy acquiring images (N=4). Some respondents were unsure whether there was the necessary workforce to deliver cancer targets. Examples were also given of the consequences of a lack of strategic workforce planning (see section 4.5.3 below). Respondents felt the Government did not give Trusts sufficient time to support the COVID recovery and that workforce strategies were taking longer to achieve than anticipated. Providing a future workforce to deliver radiology services was seen as dependent on radiology trainee and radiography student numbers, their job choices, and the composition of the current and future workforce skills and roles. Due to the pressure to meet targets and, in certain instances problems with equipment, some staff had left the NHS and were now working for agencies, which further drove up employment costs for Trusts.

The delivery of cancer targets was also influenced by the availability of a skilled radiology workforce. It was noted that there was a limited pool of staff available to work in radiography and universities' recruitment of radiographers to lecturers' posts was seen as further reducing the clinical workforce. Moreover, it was reported that Trusts were reluctant to spend three years supporting university students who might not go onto work for them *and* Trusts were cited as using apprenticeships to help deliver the cancer plan, as apprentices were local employees who were more likely to stay in the job. Further workforce measures to meet targets included the growth of other roles to fill gaps, such as reporting radiographers and assistant practitioners. One example of the impact of efforts to meet cancer targets was that less experienced radiographers were moving more quickly into specialist areas. An interviewee commented:

> *'I mean, there isn't a set time [*someone stays in their 1st post in radiography]*, but it might be at least five years at one time just a few years ago, whereas now somebody might become a general radiographer and then move into CT or one of the other specialties after just a few months. And that's, well, partly because of the cancer care requirements so the imaging departments have to provide the cancer care services and because that's high priority then they prioritise people moving into those services to make sure those services work'.*

4.5.1.3 Organisation and delivery of cancer services

Several issues were identified with the organisation and delivery of cancer services that aimed to transform radiology services and speed up reporting times (N=5), and provide new roles and ways of working and greater collaboration between Trusts, Community Diagnostic Centres (CDCs) and imaging networks to reduce the cancer backlog (N=3). Factors mentioned as hindering the delivery of cancer services were lack of capacity in terms of space, equipment, and the workforce (N=7), together with changing patient expectations, leading to more GP referrals for scans and fuelling a growth in demand. These issues had mixed effects. Although patients might be seen quicker, this placed more pressure on staff. Increased reporting turnaround times were seen as also having an impact elsewhere (N=5), potentially leading to bottlenecks in the system. An example was GPs' capacity to see patients about their test results. As one respondent explained: '*the referrers* [GP surgeries] *are saying, "Don't tell them to come any sooner because we haven't got capacity".'* Overall, demand management was considered not to be working, risking service saturation.

The need for radiology services to have the right staff and equipment, for the equipment to be fully utilised and for staff to plan its implementation and location carefully were also seen as important. Examples were cited of scanners that did not have enough staff to run them, or staff not being consulted about the purchase. A respondent stated: 'It's *not clear what that CT scanner is doing, who's is running that CT scanner? Who's reporting? Who's commissioning it? It's quite embarrassing, it does not make you feel invested'*. Another interviewee noted: '*When I asked my boss I said, "How are we going to staff this?" because we've got this lovely new scanner, and they said, "We haven't done a workforce plan." And you just think, well why not?'*

4.5.2 Strategic workforce planning

The strategic workforce planning theme included: lack of strategic workforce planning; influences on planning; and challenges for workforce planning.

4.5.2.1 Lack of strategic workforce planning

Respondents noted that strategic workforce planning was now more of a priority. There was some optimism about such planning, with one interviewee reflecting on opportunities for Health Education England (HEE) to change the ways it planned. Integrated Care System (ICS) involvement across West Yorkshire was thought to offer potential for real workforce change, provided that previous workforce models were discontinued.

There was, however, a consensus that strategic workforce planning was not as good as it needed to be. It was considered 'too dispersed' (N=10), 'disjointed' and 'last minute' (N=8), with an operational, rather than a strategic focus (N=9) and there was a perceived disconnect between strategic, regional, and operational planning (N=6). Respondents also pointed to insufficient corporate level support for clinical service units, which some felt resulted in a lack of insight into what it takes to run radiology services (N=5). Workforce plans were described as out-of-date and no longer appropriate and some trackers were considered complicated to work with. A respondent stated:

> *'I just want a simplistic model of this is how many procedures we put through a room, this is how many rooms we need to build a service, and this is how many staff we need to do it, and then we can start adding on what addition we'll need for additional capacity, what we'll need for annual leave and sickness, which doesn't always get incorporated, you'd be surprised, into workforce planning, and then we can work it back from there'.*

A lack of understanding of the requirements of workforce planning was mentioned by respondents (N=5) and some thought there was an undue focus on finance rather than workforce.

Staff did not always feel involved or engaged with workforce planning, and it was sometimes described as reactive, based on previous workforce numbers, rather than the current staff required or the skills needed. An interviewee explained:

> *'So, every ICS has to develop a radiology and imaging workforce plan, as part of the national picture. But those are being collated at a regional level, and then obviously national level. But the key thing is that they have to plan ahead. Actually, in terms of delivery, it's really hard, because they don't necessarily think strategically around what skills they need. They think traditionally around bums on some seats, and the potential expansion of services, or a new hospital, or new equipment, they don't necessarily think about a change in skills'.*

Many felt there was a need for a workforce strategy in which, *'more people [*would be] *working differently in an inclusive and compassionate environment'*(N=8). However, there was considered to be a lack of *'joined up thinking'* , involving many organisations that did not communicate with each other sufficiently. Furthermore, a lack of strategic workforce planning was identified as a challenge in relation to developing new services and avoiding staff shortages. One respondent explained that in the previous system, as new surgeons were appointed the implications for radiology would be considered, but this was no longer happening.

4.5.2.2 Influences on planning

Several factors influenced workforce planning. Radiographers and radiologists increasingly worked across boundaries and organisations (N=8); there was also an increase in hybrid working (N=5) and outsourcing imaging to companies to meet cancer diagnostic targets, given pressures on acute Trusts (N=9). An interviewee noted that: *'nationally, we are working to a three-year spending review plan, and agreement around funding. So, it's the first time we've been expected to really clearly workforce plan, and actually deliver numbers of staff, not just for this year, but for next year and the year after'.* The impact of COVID for strategic workforce planning was discussed in terms of both current and future demand for radiology services.

4.5.2.3 Challenges for workforce planning

The challenges for workforce planning were described in terms of changes in technology (N=11) and the limitations or benefits of AI (N=11) and the implications of these for work design and workforce skills. Further challenges were lack of clarity in strategic plans for radiology and ongoing changes in radiology service delivery, with greater involvement from primary care. The implementation of Community Diagnostic Centres (CDCs) and the separation of acute from elective activity led one interviewee to state: *'it's understanding what a radiology service will look like in the future'*. As previously mentioned, there were not always sufficient staff to operate equipment and undertake reporting. For example, it was claimed that, due to a shortage of sonographers, diagnostic radiographers were being skilled up, a development that constituted, *'pinching Peter to pay Paul'.* Another challenge was the lack of radiologists and radiographers in management roles. Respondents believed that radiology services could not be adequately managed by other professional groups [such as nurses] because they did not have the requisite insight into the challenges facing radiology services.

4.5.3 Workforce roles and skills

The theme of workforce roles and skills included the issues of flexible and agile working. The importance for service delivery of an agile and flexible radiology workforce was mentioned by all respondents. The kind of flexibility required were: staff working different hours, staff banks, part-time working, staff increasingly working across different Trust sites (N=7), and use of remote and hybrid working. Staff working flexibly in this way were thought to need a broad range of transferable skills, as one respondent explained:

> *'A radiographer is still going to be a radiographer. The big thing is around the flexibility and agility to be able to move into other areas of practice.* The *increasing demands of cross-sectional imaging are historic, we've trained people to be a general radiographer to work in x-ray for years, and then they move into a speciality. But the expectations that actually the first time we will require them to have more flexibility in terms of where their career options are…. So, I think there is a big challenge for us around that work'.*

Whilst the above quotation points to the need from services for flexibility, the following example shows that flexible working (e.g. working from home) could also cater to staff members' needs:

> '*You don't actually need to come into the office to review an x-ray. You can do it from home with the right equipment. and people can work flexibly around that. A shift away from you sat at your desk to "Oh, I've reviewed... you sent me a task of doing 20 reviews today. I've done the 20, but I did two when I got up at 6 o'clock. I dropped the kids off at school. I then did whatever. I then picked them up from school. And then I started it again in the evening'.*

Both flexibility and a work-life balance were mentioned as important factors to accommodate the changing requirements of the radiology workforce. It was considered important to appreciate that at different stages of their life people required varied types of flexibility. For example, a respondent mentioned how *'lots of people like to work nightshifts because it worked for them'*, whereas for others '*Long days and nights [are] exhausting, people get worn out and start going off sick'*. It was thought that patients, as well as staff, could benefit from such approaches, because staff who felt supported were better able to care for patients:

> *'the knock-on effect was improved patient care because we gave staff flexibility around the hours that they worked, when they worked, and recognised that people had lives. We invested in them heavily. Lots of training courses. Lots of development'.*

Different attitudes to flexible working had been encountered, depending to some extent on the professional group, where staff worked, managers' attitudes to flexibility and levels of trust in the appropriate use of flexibility. For example, one respondent described a lack of flexibility:, *'I must be there at 8.30 and I go home at 5 and we shall not deviate because our manager doesn't like it at all'*, whereas other interviewees cited positive examples of flexible working.

Although, as noted above, agile and flexible working was often welcomed and recognised as important both for services and staff, there was also a view that flexibility had to be carefully managed., For example, some respondents highlighted the importance of staff visibility on-site and of the need for face-to-face contact: '*Registrars need face to face contact with consultants'.*

4.5.4 Service transformation

The theme of service transformation contained the issues: changes, challenges, and solutions. Some of the issues discussed in this theme overlap with ones that have been previously discussed by interviewees.

4.5.4.1 Changes

Several key changes that were already transforming or had the potential to transform radiology service delivery were identified. These included growth in the assistant practitioner role (N= 8); a view that all roles in radiology services were changing with technology (N= 8); increased digital working (although respondents were unclear what this would mean long term, or the implications for workforce numbers and training); and increased use of technology and AI leading to a '*quick turnaround*' of work. Another change was that some areas were reviewing how imaging slots were utilised and the appropriateness of referrals.

Some of the changes cited had workforce implications, such as radiology consultants working out-of-hours more frequently. In addition, it was noted that Integrated Care Boards (ICBs) were driving benchmarking and learning, reducing doctors' input in MDT meetings so that they could concentrate on clinical activities, and including radiographers more often in MDTs. A quote illustrates the point:

> *'The other change that I can see happening and we've been very slow to embrace, but I think is going to absolutely have to, is the out-of-hours work. So, I think we have not embraced seven day working at all. As I said, our registrars absolutely pull the brunt for us and we still work on an on-call model, so we still do 24-hour calls, weekends on-calls rather than… I think we are going to need to do much more out-of-hours on the shop floor, evening shifts, daytime, weekend shifts rather than an on-call thing'.*

The role of different organisations such as CDCs, Imaging Networks and Radiology Academies were also mentioned in terms of changes to how and where radiology services was delivered. CDCs as a potential solution to the challenges that radiology services face are discussed further in Section 5.2.

4.5.4.2 Challenges

The challenges identified with delivering diagnostic cancer services included: the volume of work (N=11), the lack of strategic workforce planning (N=8), staff shortages in all areas (N=10), time and capacity (N=7), the technology and funding to support change (N=8), the variability of workforce planning skills (N=3), and some radiology roles not being fully utilised, for example advanced practitioners or assistant practitioners. Workforce challenges were also linked to changes in training and subsequent shortages of staff, professional regulation (HCP) hindering workforce flexibility and the implications of broader changes occurring in radiology.

Challenges around trying to implement culture change and the *'Lack of buy-in due to risk aversion'* (N=4) were also seen as impeding service transformation. The culture between different professional groups was sometimes challenging, with one respondent pointing to tensions between reporting radiographers *and* radiologists*: 'some radiologists are incredibly supportive, other radiologists are not at all'.* However, effective teamworking, collaborative professional working and promoting a multidisciplinary team culture were considered to be strengths. Both leadership and training were suggested as solutions to help foster cultural change. Interviewees commented that change within the NHS from competition to collaboration was driving some service transformations, with Trusts and other organisations, as well as staff, working increasingly together.

Respondents noted significant workforce challenges in terms of ensuring staff wellbeing and retention, the continued planning of the workforce around equipment, rather than changes in service delivery, different types of flexibility and ways of working (N=7), ongoing competition for lower-banded staff from private sector or retail organisations who can offer competitive rates of pay. Radiologists reducing their hours and retiring early was linked to pay and issues around pensions, which encouraged doctors to work part-time *'.* Similarly, there were challenges for radiographers around pay and roles, especially in terms of commensurate pay for reporting radiographers, compared to radiologists:

> *'I'm not going to pay you the same as I'm going to pay the radiologist, because they're radiologists'. I think that needs to change, because if you're going to recognise that somebody is, say, a consultant radiographer, then I think you need to have a real good look, hard look at the responsibilities and pay them in line with that'.*

In some cases, a lack of clinical acceptance of new roles meant they were not fully utilised, and this required acceptance by different professionals of their respective roles. A respondent observed: '*radiographers are just as guilty of it as perhaps radiologists toward radiographers, being prepared to shift what it is they do and what their focus is'.* A combination of factors such as COVID, staff being overworked and high demand for radiology services caused respondents to regard staff members' ability to innovate or manage change as limited, owing to lack of capacity. While the pace and volume of radiology work meant faster screening and reporting, staff could become '*overwhelmed with all the information'* leading to inefficiencies. Transformations in radiology services were also discussed in terms of new models of care for screening services, AI, personalised medicine, and acute care versus public health. Clinical pathways and care closer to home were considered to be transforming services, but caution was needed because, as an interviewee explained: '*Taking a workforce from one area could destabilise another service if not done collectively',* requiring strategic planning and collaborative working.

4.5.5 Recruitment and retention

The issues associated with recruitment were linked to the recruitment process being too slow (N=8) and potential recruits being lost. The lack of radiology posts was noted, and a respondent remarked, *'so for the last few months it's been like; "there's no jobs. You can't have any jobs", but it's now changing'* (N=3). One respondent suggested, that recruitment to NHS posts could become harder as other sectors competed for staff due to shortages in the wider labour market:

> *'The NHS is going to have to fight its recruitment battles now, it's going to have to get very much more attractive. And also, we're very good at putting barriers for recruitment in health. But it's very slow, Aldi will appoint you in a week? The NHS, it's six weeks if you're lucky and that's active, fill the form and I done this and that, well, we're going to have to stop all that'.*

Interviewees mentioned that locally trained staff were more likely to remain and other possible retention strategies might include a good working environment, good team working, offering car parking or 'up-to-date equipment', *'being listened to and your voice heard'* and *'supporting CPD'*. Although the NHS was considered, generally, to be offering good pay and working conditions, both radiologists and radiographers often had multiple job offers and '*can pick and choose where they go which still includes working for private providers'.* The issue of budgets was also discussed. Some constraints [not in all Trusts] limited flexibility about how budgets were spent and had implications for retention, as an interviewee reflected:

> *'You're over-spent in one budget or under-spent in another, finance don't really get that. If you suggest, well, all right then I won't do that, but can we have some training monies in a separate pot to use just for developing posts? No, you can't do that because you have to have vacancies to have the budget to develop anybody. So, the finance teams are a bit, doing things as they always did, really'.*

Another example cited with budgets is that staff recruitment may span different financial years and it therefore a balance had to be achieved between recruiting staff, managing current staff turnover, avoiding overspend and delivering services.

Problems with retention were also linked to limited work flexibility, dysfunctional teams, students or trainees not fully understanding what coursed involved and staff not being valued, particularly by line managers. This could lead to what was described as a '*toxic workforce*'. An example illustrates this:

> *'Thanks for coming to work, but we're going to charge you for parking. Eat healthily, but the only thing available in the canteen is..." You know, "We value you, but, no, you can't have that kettle on your ward'.*

Offering different types of flexibility was seen as key to recruiting and retaining staff, which involved ensuring sufficient supply lines and staff deployment through rostering and job planning. At the same time, problems with retention included radiographers accessing opportunities to experience other modalities, leading to staff moving to more lucrative grades (N=4). The employment of radiologists was quoted as a '*big financial commitment'* and was sometimes delayed. A few interviewees felt less experienced radiography staff tended to move around and were '*fickle and they'll go wherever they think it's a slightly better offer'.* The 'retire and return' scheme had some benefits as it offered flexibility, but due to tax limits on earnings some staff could not take on more work. One respondent noted that whilst the NHS could not compete with some of conditions offered by the private sector, it could develop people in their professional practice and offer specialist skills training. The need to support staff and provide appropriate pay were also cited as both recruitment and retention strategies:

> *'It's a challenging time, and we've got to look after the staff that we've got. They're our most valuable asset. Without the staff, we haven't got a service, clearly. So, we listen to what they say and try and help'.*

4.5.5.1 Recruitment and retention of international staff

Particular issues were raised in relation to international staff recruitment. It was described variously as a '*hot topic for HEE*', a '*short-sighted grandiose idea',* and '*not a quick fix solution or a long-term answer*', with some respondents believing that the focus should be on training and investing in UK radiologists/radiographers, rather than recruiting internationals. However, many noted that there was a need to recruit internationals and, given this, interviewees talked about having '*very good experiences with international staff*'. One respondent observed: *'Our international radiologist is outstanding and without them we wouldn't have a radiology service'.* However, interviewees noted that some overseas doctors did not always have the same level of confidence as UK-trained doctors and the transition and cultural integration of international recruits was sometimes problematic (N=7), particularly since global health care systems, training and professional body requirements and equipment differed. In terms of radiography, an interviewee explained that in the UK, radiographers were trained to a higher level and had different levels of autonomy, and responsibilities than in some other countries (N=5), whereas radiographers in some countries were considered to be assistants.

Other challenges were related to the support required to undertake international recruitment. Several respondents considered it *'onerous and time consuming'* and it did not necessarily lead to the recruitment of the staff required. Interviewees talkeda about needing to be aware of the country-of-origin staff were being recruiting from and the implications in terms of education planning, cultural sensitivity and providing an upskilling plan. Some noted that providing pastoral care can add significant expense to employment costs. Entry requirements, visas issued for only three years and international recruits seen as transient and having to *'decide whether to stay or go'* were further challenges. International recruitment was described as *'slow'*. Some UK geographical locations were regarded as not having the same recruitment 'pull factor' and respondents reflected that their Trusts were not always international recruits' first choice. There was also some concern that there was an over-reliance on international recruitment:

> '*It's healthy to have a strategy that does include some international recruitment, but I don't think it should be the absolute necessity because it's great to be able to have a flexible workforce when needed. But the thing is, our plans are heavily built on them, on international recruitment'.*

Ethical concerns were expressed about 'poaching' staff from countries that were '*struggling to provide their own workforce'*, the lack of protection for some international staff [this depended on the recruitment process] and the potential for them to be exploited. Practical issues that can confront an international recruit were also outlined, such as the cost of housing and living in the UK, relationship building, cultural and environmental differences.

4.5.6 Universities

The issues identified for the theme of universities were: education and training and clinical placements.

4.5.6.1 Education and training

Interviewees noted that the role of universities was to deliver education and training that prepared the current and future radiology workforce with a range of skills and knowledge. Universities contributed to workforce planning by supplying the radiology workforce (although some felt that the current student/trainee numbers would not meet service demand), they determined radiography student numbers, and provided students/trainees with a variety of experiences in terms of theory and national best practice standards. Education and training were regarded as '*not just skills acquisition'* but ensuring that students were ready, '*for the world of work, not only now, but in the medium-term future'.* Interviewees commented that universities needed to prepare radiography students, as active learners, for cross-boundary, flexible working, with the requisite skills and knowledge at HCPC standard.

The expansion of imaging services required more training to supply the workforce (N=8). An interviewee commented that: '*imaging departments are growing almost exponentially and there is a need for more people in CT, MRI, ultrasound and we're struggling to provide from the pool of graduates'.* The question of who would provide the education and training for the future radiology workforce - e.g., further, or higher education – was also raised and there was a view was education should not be about '*one size fits all'* but, rather, should focus on widening the recruitment entry gate and attracting the right students/trainees to courses [it was thought this may address the non-completion of radiography students]. Equally, the necessity for universities to work collaboratively to provide the programmes radiology services need and students want was mentioned N=4). Examples were cited of Trusts having to send apprentices to other parts of the country to access the courses required. An interviewee noted:

> '[universities] *you're designing to sellers, we're your customers, but you're not giving us anything that we really want to buy. What we really want to buy is some kind of accredited qualification for that undergraduate layer of staff that is bankable, so you can APEL your points across and become a radiographer'.*

Another situation discussed was that training did not always meet the workforce requirements of diagnostic services. For example, to undertake ultrasound *'you have to train to be a radiographer, and then you do a post-graduate qualification'*. A respondent remarked:

> *'There's a university's that already has got an undergraduate ultrasound degree. So, that's transformational, it really is, because why put somebody through three years of training that, yes, they'll know how to care for patients, talk to patients and some of the anatomy things, but what they want to do is ultrasound, so don't teach them how to take an X-ray'.*

Issues identified with the provision of education and training included problems when courses were not viable and therefore did not run, small student numbers, and a lack of fit between universities' education and business plans with the requirements of health and social care practitioners. A few respondents commented on the content of undergraduate radiography degrees, noting that training focused on generic content and not specialisms where many staff were likely to work, although some universities were cited as now offering a broader range of radiology programmes for different levels of staff.

Interviewees' suggestions included more education and training opportunities for assistant practitioners, an open entry route or a flexible approach that allowed more support workers or other potential candidates to train, a foundation degree for radiography support workers in addition to apprenticeships and Trusts offering more apprenticeships. To deliver education and training different universities needed to work together to reduce duplication of courses and *'to develop a coherent plan to share clinical placements/clinical resources so they can more effectively educate/train the future workforce'.* It was anticipated that universities would work with Imaging Academies in upskilling the current workforce, particularly advanced practitioners.

Further suggestions included more joint training of radiographers and radiologists, providing radiography students with an opportunity to experience different clinical areas so they could consider different career pathways. It was thought that this approach would avoid silo training that restricted career choices and would allow people to move into different roles more easily. A few noted that radiography does not have, but needed, a national preceptorship programme:

> *'We need a national preceptorship that actually standardises things and then have a career framework within 5/6/7 for those that want to go then into management and into other things and then the advanced practitioners come in at 8a and above'.*

4.5.6.2 Clinical placements

Education and training issues were linked to strategic workforce planning, preparing the radiology workforce to be digitally literate, meeting cancer targets and joining up training for both radiologists and radiographers. An example cited was that in radiology there was an *'expansion drive, but at the same time, they're also trying to do a levelling up'* which meant that some areas of the country were '*being told to reduce the number of training radiologists, while other areas need to expand'.* This had potential consequences for the number of trainee radiologists on courses. At the same time, an increased number of trainee radiologists were opting to train part-time and therefore extending their training period, which had implications for overall training numbers as the system operates as *'one in one out'* for consultant workforce numbers. The GMC had contended that 'too many subspecialists' were being trained and there was a need for more generalists, and, as a result, *'radiologists are expected to maintain more breadth rather than a specialism'* which could have consequences for diagnostic cancer treatments.

The problem with finding clinical or training placements was discussed by respondents in terms of Trusts' capacity to take students/trainees and provide mentors and support. Issues included a lack of placement capacity (N=7), clinical providers feeling stretched and *'very reluctant' to take more students' (*N=5) and *'opposition from placement providers who have to provide placement areas support'* (N=3). One interviewee observed that trainee radiologists could '*struggle to access hands-on stuff'* and finding placements was often about persuading hospitals to take radiology trainees: '*People enjoy the training, but they just don't have the time and they don't want to take on additional things'.* Radiography experienced similar problems, but post-COVID NHS Trusts were considered more willing to take students. However, one interviewee remarked, '*there is still some resistance from frontline staff as there are fewer of them to train/support students and they are 'struggling'.* This was exacerbated by the reduced number of clinicians to support students/trainees due to post-COVID workforce challenges such as staff burn out, early retirement, supervisors prioritising clinical work, staff moving out of clinical working into education and increased student numbers. At the same time, the increase in apprenticeships across Trusts was noted as having an impact on placement capacity and mentoring. Moreover, a growth in the number of universities in certain areas offering radiography courses had placed additional pressure on clinical placements:

'It's taking away placements from the current providers' 'offering enticements to the Trust to take their students' 'scrambling around after the same placements and poaching placements from the traditional provider and that is not a recipe to solve the workforce problems'.

As a result of the pandemic some explained there had been a change in approach to clinical placements, with many universities having invested in simulation for radiography students. The effect was described as: *'suddenly we become agile in terms of clinical placements, and the investment around simulation and the expectation that actually a placement isn't just being put in a room with a radiographer, a placement can be a whole raft of things'*. The advantages cited with simulation were that students' went into placements more prepared and picked up skills quicker. Consequently, simulation suites and investment in new technology helped to reduce the time radiography students needed to be in a hospital setting as they were acquiring skills in different ways.

4.5.7 AI

Respondents talked about the potential of AI, problems with AI, and workforce issues.

4.5.7.1 Potential of Artificial Intelligence

All respondents discussed AI (N=11) in terms of its benefits and problems and the future role it will play in radiology services. It was anticipated that AI would supplement the workforce, e.g., by assisting reporting and decision-making around reporting. Furthermore, AI was seen as contributing to service delivery (N=9). A respondent commented:

'As far as the cancer plan is concerned AI has got to be a big plus […]. There are bottlenecks and one of the bottlenecks is the physical ability to scan the patient, you know, how many scanners have you got, how many members of staff have you got, how long does the scan take?'

AI was perceived to have the potential to change patient pathways and make efficiencies. Other cited benefits included: AI's use in reporting and as a triaging tool, making reporting being better ordered (N=7) and reducing errors, thereby ensuring quality standards. For example, AI could provide better image interpretation (N=7). This quote illustrates the point:

'But certainly, in the way people are thinking about it, particularly around reading, around that second read, and it's always if you have two reads, you're always going to be more accurate than having a single read. So actually, having a second read that's technologically of a consistent standard, is always going to be a good thing at the moment and for the foreseeable future, it will always be human trumps'.

AI was also seen as a useful means to undertake mundane, repetitive roles to free up radiology/radiography staff, to reduce bottlenecks and increase productivity. Potentially work turnaround was quicker as with AI: *'you could scan a head in literally a few minutes, somebody looks at the data from the images produced to decide if there's anything unusual'.* The following is an example of some of the AI developments outlined:

'We're looking at whether the automated intelligence on the PACS system will be able to interpret and then just one radiologist or one reporting radiographer report. It'll transform massively an area that we've got significant workforce challenges'.

Consequently, radiologists/reporting radiographers could concentrate on abnormal findings. There was also a possibility that AI patients could get their results in real-time (N=2) and AI reduced repeat diagnostics, *'which is wasteful and not appropriate for patients, and we can't afford it' (*N=3). An interviewee observed that it was not always clear why people were reading all results and felt it was due to risk aversion: '*Technology should be reading 90%'.*

Both CT and MRI generated a lot of information and there was a view that this was: '*phenomenal compared to previous equipment, artificial intelligence is really the only way forward in terms of gathering all that data and looking at all the data and looking for anomalies'*(N=5). The use of AI algorithms was also mentioned as supporting diagnosis, and some were unsure why they were not used more. Examples were provided of AI helping with the supervision and training of radiology/radiography students by enabling staff to supervise remotely: '*Allowing a remote radiographer to supervise assistant practitioners doing CT lists with technology that allows them to oversee their work without being in the same physical room'.* Changes occurring in work design due to AI included CT scanners being managed remotely, using cameras to establish patients are correctly positioned, patients interacting with assistant practitioners rather than radiographers, or a radiographer in training doing more work, overseen remotely by an experienced radiographer, looking at 4/5 different scanners at the same time and helping when required.

Many believed AI would automate radiology processes, enabling radiographers and radiologists to carry out other work, but some mentioned that humans would always be needed and were concerned about the boundaries between human and AI roles. They stressed the importance of ensuring that the patient caring aspect of radiology services was maintained, as a respondent observed: '*it's still that coming to a hospital, I mean a smile, a helping hand onto the examination table, just someone chatting with you'.*

4.5.7.2 Problems

The problems that interviewees mentioned with AI included that some people were unclear about the impact of AI for radiology services (N=7), did not know a lot about it (N=6) and were unsure who to ask about AI (N=5). Some noted that AI was '*Still way off actually making a clinical decision not to report things'* (N=4) and that it would be some time before AI helped with capacity and demand issues in delivering radiology cancer targets.

Further problems were that both students and staff lacked digital literacy and were not prepared for AI. An interviewee suggested: '*we've got to be careful that we don't create computer says "yes" when it shouldn't have done, and the role of the practitioner is to make sure that others don't fall into that automation bias kind of idea'.* Some were concerned that if practitioners become more IT literate '*It might make radiography programmes to be techier than they need to be.'* Another interviewee reflected:

> *'That's where things get really scary, you know, is there going to be a need for anybody to actually look at these scans to see if the super computer's right? And the feeling at the moment is that all findings will have to be second- considered by a medic or somebody who's trained to do that. That's the scary bit and that's, you know, where is that going to go?'*

Another problem was that uptake of AI in the NHS was slow and mixed. Some felt that not much was happening with AI but *'those that are doing it are pioneering and probably at great expense' (*N=3), while others argued that a lot was happening, but people did not recognise it as AI. The cost of AI and whether Trusts had the resources and finances to use it was an issue and an interviewee remarked: '*I worry that it* [the cost of AI] *will limit AI progress'.* A suggestion to address this was that Integrated

Care Boards buy AI for a region, rather than Trusts investing individually. Additional problems were that manufacturers developed and sold AI products that were not necessarily what clinicians needed and that some of the equipment was not sufficiently accurate, limited in what they could do and time-consuming to use.

4.5.7.3 Workforce

The issues identified with the workforce and AI related to how it was changing the roles of radiographers and radiologists, although there was still some uncertainty long-term about its implications and a belief that AI was not a substitute for radiographers or radiologists (N6): '*I think any of us who think that AI at some point could do what we do are deluded'* (N=4). There were mixed views on whether there was still a need for staff to look at the AI findings *to 'check how right it is' (*N=5) and that although radiography has always used technology: *'it's still a caring-based profession so needs people who can care'* (N=3). The increased number of litigations from radiation incidents and a perceived reluctance to share information in some areas of the AI industry were raised and it was suggested that a role was needed *'for radiographers to actually supervise any kind of automated technology and understand what it's doing and what decisions that technology's making'.* Consequently, some believed that AI was being used to make up the shortfall of staff, leading to a concern about substituting radiology staff with AI/technology for certain roles. The alternative view was that AI is *'something to help, not something to take over, if we use it well'* and that in areas where it was difficult to recruit radiology staff, AI offered a solution. There was agreement that radiographers and radiologists who embraced AI would do better than those who did not grasp the technology, as '*they're getting pushed out and IT people are doing those roles'*. The benefits of AI for the workforce were described as:

> *'We talked about a supercomputer doing some of a radiologist's job, which will allow them to get out and do the hands-on stuff, which takes the radiologists back to being proper medics, in a way. Now they're actually doing what they're trained to do and to do stuff with the patient'.*

4.5.8 Summary

The interviews generated a wealth of rich data, incorporated into the themes and associated issues. The issues were interconnected, with several consistent topics apparent throughout, especially in relation to the rising demand for radiology services and problems in meeting cancer targets The various solutions proposed by respondents to these and other challenges will be discussed in Section 5.

5. What possible solutions are there for addressing the gap between the required radiology workforce and the projected radiology workforce?

During the interviews we explored with respondents their views on solutions to address the gap between the required and projected radiology workforce. A range of measures were discussed to help meet cancer targets and included: new ways of working, upskilling and new roles, Community Diagnostic Centres, recruitment and retention of the international and UK workforce, and collaborative working.

5.1 New ways of working, upskilling, and new roles

Overall, there was a consensus that staff shortages and increased work volume in radiology services meant the workforce needed to be upskilled, new roles created, and different ways of working instigated, together with developing skill mix.

5.1.1 Upskilling

Generally, respondents believed the benefits with new ways of working and upskilling staff included a broadening of the scope of practice, making jobs more interesting (N=5) and that the pace of technological change, across every modality, meant that staff did not become 'deskilled' and could be rotated around areas to maintain skills and provide job variety. Some Trusts were reviewing the skill mix model used in relation to jobs and recruitment to gain a better understanding of the appropriateness of the roles and who was required to undertake them. An example given was:'*upskilling radiographers and staff substitution, removing routine work 'giving it to someone else so a radiographer can concentrate on work needing higher skills'*. Another respondent observed:

> *'there's nothing worse than just being on a bit of a treadmill, clearing waiting rooms and all that kind of thing that comes with it. Who wants to be staring at hundreds of slices of CT grains, in and out all day, when you can take some of that pressure off by working closely with somebody and creating a team that makes, at the end of it all, makes you look good as well?'*

Skills were required at different levels [dependent on profession] pre-registration, support worker and assistant practitioners and radiographers registered at enhanced, advanced and consultant level. The reasons cited for upskilling radiographers were ongoing workforce shortages (N=8) and a focus on upskilling staff to meet service needs. A blurring of role boundaries between radiographers and other health professionals *(*N=5) was mentioned, with radiographers expanding their roles to undertake work previously provided by radiologists and increasing their autonomy and job satisfaction. Examples cited included imaging reporting, reporting chest and abdomen and some radiographers reporting at MDTs, although it was noted that some Trusts? were more willing to upskill the workforce than others. Changes in role boundaries were discussed in terms of different professionals and it was pointed out that upskilling could be met with resistance where professionals '*did not want to lose that work.'*

There was agreement that radiographers needed to develop skills to meet HCPC requirements (N=3). Similarly for radiology, there was a reflection that the role had changed over the last twenty years, with radiology becoming a consultant-led service' so that, *'on the day everything is checked by a consultant and that's a huge change'*. Furthermore, due to the *'increased volume of work, radiologists are more strategic and planning rather than the actual reporting and running sequences'* (N=4).

Some reservations with changing skills and roles were noted: the problems with different professional groups taking on too many skills/roles and losing their identity, upskilling left some staff with 'hyper-acute' work that was, '*really stressful to maintain and needs to be addressed by appropriate job planning'* and that any expansion of roles required others to fill the gap. A few observed that, '*Radiologist leaders don't like this' and they argue there is a need to train more radiologists'*. One interviewee recalled difficulties when refusing to take on a role: '*I was called awkward'* [for not doing something], *we have to be careful that they're not being told things from all directions as you have to do your own job'.* However, most respondents felt that a positive team-working relationship between radiologists and radiographers addressed this issue.

Some respondents discussed that compared to nursing there had been a limited expansion of the radiographer's role and that radiology services needed to be *'braver about different skill mix'.* Some examples cited were that in the radiology specialisms skill mix had not been fully introduced or that radiographers could be more fully utilised and have '*better opportunities to develop their role'*. At the same time, it was necessary to support people to work at the top of their scope of practice e.g., *'making the best use of reporting radiographers'.* An alternative view was that not all staff wanted to be upskilled:

> *'I don't think all the workforce will want upskilling. I think that's the main thing to say. Some people will be quite happy to be a band five radiographer, and you need people like that in your team. Not everyone wants that promotion'.*

5.1.2 New and emerging roles

The new and emerging roles discussed for radiographers were enhanced, advanced and consultant roles (N=8) and assistant practitioners and apprentices were regarded as supporting the radiology workforce (N=11). Enhanced and advanced practitioner roles were described in terms of upskilling, with clear differences between their skills and roles outlined. Staff working in other fields of radiology such as nuclear medicine and sonography were mentioned and the importance of appreciating that, '*other people can do the job with different qualifications'*. There was a perspective that for radiographers '*enhanced practice will always be a bit bigger than advanced practice'.* However, an interviewee explained:

> *'Advanced practitioners are a new generation with very different skills, because we've established a set of skills now that we expect somebody who is an advanced practitioner to do.*

Whilst there was agreement that there would be more advanced practitioners in radiology services, *s*ome respondents observed that advanced practitioners' roles and skills were not always fully utilised and sometimes there were problems with them not taking what was described as *'advanced practice clinical decisions'* and '*not fulfilling the four pillars of advanced practice'.* In contrast, another interviewee used the example of radiographers working at the '*top of their licence*' but felt there was a need to move away from that language because '*we're human beings and we can't do that [work under pressure all the time]. We need to have days when we do less and days when we do more'.* The suggestion offered was developing new roles and using job planning to better allocate work. There was also an issue about the mismatch between roles, titles and pay. The need for managers' buy-in (N=5) was considered important as this helped with developing and accepting new roles.

The roles of radiographer/radiologist were generally seen as supportive to each other and involved delegated responsibility *(*N=5). Radiography was not necessarily seen as a *'threat to radiology',* but an opportunity to expand the provision of services (N=4). An interviewee explained that it was important to have 'acceptance' between radiologists and radiographers: *'sometimes, well this is my responsibility, keep your nose out kind of thing. It takes time to get a level of acceptance'.* A suggestion offered was the creation of a Royal College of Medical Imaging, with radiology and radiography as subsets within a single professional body, which would also include assistant practitioners, together with a career framework for radiology staff. However, an interviewee felt, *'it won't happen',* due to vested interests.

All respondents mentioned the expansion in numbers of assistant practitioners and apprentices and the potential to increase further. The advantages with assistant practitioner roles were discussed in terms of giving band four staff job opportunities and enabling radiographers to undertake other roles. Examples were also given of bespoke apprenticeship programmes in MRI/CT for assistant practitioner radiographers and new roles. The proposal was that 'simple tests' in MRI/CT would be identified and triaged to assistant practitioners or they would support radiographers, so in some cases rather than two radiographers it would be an assistant practitioner and a radiographer. An interviewee explained:

> *'We are also looking at some of our assistants as well, and we're just re-evaluating all the assistance job descriptions, the band two and the band three in particular, to review what's appropriate within those roles, and have we got those quite right'.*

Respondents also noted significant variation around the utilisation, authority, and scope of practice of the assistant practitioner and support workforce (N=4). An example of staff working at Bands 2 and 3 illustrated the point: '*trying to define their role and responsibilities isn't easy because Trusts let them do some things and others don't*'. This was linked to concerns around assistant practitioners working beyond the limits of their responsibility (N=2). However, some suggested such problems were being addressed through clearer roles and responsibilities and advocated registration of the assistant practitioner workforce and the need for them to work under the supervision of HCPC registered radiographers (N=5). Even so, practical issues around ensuring sufficient supervisory staff were raised:

> '*Because of the radiation, because you're required to have a degree to be autonomous with radiation, end of, but there's too many incidents, isn't there? And if they recruit too many Band 4's then students can't be supervised by a Band 4 or an unqualified member of staff then that has the implication of not being able to have your supervision in practice, it'll reduce your student numbers. It's a knock-on effect, isn't it?'*

Most participants talked about the potential for apprentices to fill radiology service vacancies. Apprentices tended to be local employees, often recruited from the radiology area they were working in, who learnt on-the-job and were already familiar with Trust working practices. Overall, apprentices were considered to offer a good a return on investment and one respondent reflected that *'within five years the way that HEE is moving it everything will be on apprenticeship'.*

Several suggestions were proposed to support and encourage the assistant practitioner role. There was a need for a career structure, particularly for assistant practitioners working in radiology services, and it was essential to ensure that assistant practitioners felt valued and fairly treated.

There was a consensus that new roles were emerging (N=10) and there was an opportunity for portfolio careers (N=1). As mentioned above, these new roles included the support and assistant workforce (N=8); further, the growth in imaging requiring more radiologists and reporting radiographers to meet cancer targets. Emerging roles were also described in terms of changing careers and different career options for radiographers around enhanced, advanced or consultant practice (N=9) together with an increase in the scope of practice across groups, *(N*=6). Solutions offered to address workforce challenges were: more apprenticeship schemes, vocational options, and a change in mindsets: '*sometimes it's the change management of the situation that will ultimately be the transformation'.* The provision of leadership support to all staff through the Leadership Academy, particularly for staff at lower grades who were expected to supervise and manage. Dedicated Practice Educators were needed to support students/staff, as well as consultant radiographers focusing on the development and training of trainee radiologists. Several respondents felt that integral to developing new roles was a culture that promotes support: '*a need to be kind to each other instead of just always thinking the worst of others, not that we necessarily do that, but it's in part because people were under strain isn't it?'.*

There was a view that artificial intelligence may help reduce some of the work of radiographers who in turn might become more of a '*healthcare scientist'* supported by an assistant practitioner workforce. However, there was uncertainty about whether this would reduce radiography workforce numbers, and some feelings of trepidation were expressed about this potential development. Roles such as Practice Educators supporting students and experienced staff were important and the potential to develop administrators or assistant practitioners to take on Navigator roles at Band 3 *(*N=4). Physician's associates, working under the supervision of radiologists, were also proposed. Respondents commented that the Richards' Review had argued for an increase in CT scanners and, to deliver this, a new supervisor role could be created to oversee radiology services in areas such as A & E. An interviewee pointed to the need to enhance the role of the radiographer in supervising technology *'because technology will make more decisions, but the radiographer will be responsible for the decision of the technology'.* Another idea to support these new roles was a Skills Escalator that would offer a continuous career pathway for all grades from apprentice to advanced practitioner (N=5). New roles would also be shaped by new technologies and artificial intelligence but as one interviewee noted: *'It's how to utilise these technologies, how do we get the best of it, but not lose patient contact'.* The need for more radiologists to get more involved with leadership and management was also raised:

> 'It's *hard because doctors don't want to leave, don't want to deskill, they want to retain their skills – we've got this kind of weird disconnect, it happens in all medicine, you know, nurses tend to go into management, and doctors don't, radiographers tend to go into management, radiologists don't, and it's not very helpful, because you don't create good, kind of, multidisciplinary teams within the management'.*

5.2 Community Diagnostic Centres

Community Diagnostic Centres (CDCs) were also seen as a solution for workforce issues, potentially transforming radiology services in terms of where and how diagnostic services would be delivered. A respondent explained: *'for example, patients with cancer, the CDC could be the place where people go for their first surveillance scan rather than coming to the cancer centre'.* Interviewees explained that CDCs could move some non-acute work and primary diagnostics out of the acute setting and it was pointed out that amongst NHS Trust staff there was a *'huge appetite within the workforce for them to rotate out to these CDC sites'.*

However, there were also reservations, including which staff to employ in CDCs, given the skills required, and a fear that Trusts may lose staff to CDCs unless they work in partnership. One solution offered was to use CDCs to rotate staff from busy hospital settings to less acute activity, which would assist with maintaining staff skill base and quality whilst also giving staff a break from the relentless pace in acute hospitals. Furthermore, opportunities for collaborative working between CDCs and Trusts were possible, around sharing equipment located in CDCs

Many thought that CDCs could help support training and provide a better working environment, but that any expansion needed to be planned to avoid destabilising the workforce, involving collaboration with universities and Trusts. The relationship between CDCs and Trusts could be complicated due to finance and income generation, however, given that Trusts lost income when patients were referred to CDCs:

5.3 Recruitment and retention (UK and international workforce)

Several solutions were offered to resolve challenges associated with the recruitment and retention of both the UK and international radiology workforce. For international recruits the solutions offered included a requirement for international recruitment to be '*much more accepted and mainstream'.* With HEE working on various plans for international recruitment, there was a need to have a national induction into the NHS in addition to induction processes provided by some of the sponsoring schemes, to build a system where international radiologists/radiographers were transitioned fully, upskilling staff when required, and with universities offering top-up, buddying and peer mentorship support. International recruits who came with their families tended to stay longer in the UK, so offering help to enable families to come to the UK together was thought to be beneficial. Both good support and positive experiences made international recruits more likely to settle. An interviewee stated that international recruits would think, *"This is the place for me," and they are really like a duck to water'.*

Schemes such as the Certificate of Eligibility for Specialist Registration (ECESR), various medical training initiatives and the global fellowship programme, together with supporting radiologists to get consultants posts had worked well and were regarded as successful initiatives for recruiting radiologists. For example, the global fellowship programme was described as, *'three parties involved, an international healthcare system, the radiologist, and the UK healthcare system. So, it should be beneficial for all sides'.* These organisations, together with NHS Trusts and HEE, worked to recruit international radiologists. As part of the three-year programme radiologists work in general radiology and also gain sub-speciality experience. The benefits cited were that radiologists worked for the NHS, contributed to delivering radiology services, gained new skills and that nations benefited if the radiologist returned to their home country. Alternatively, radiologists may stay and be employed as *'homegrown'* consultants. Equally, the involvement of HEE in international recruitment [see Global Radiologists Programme] was regarded as providing *'a protected system more likely to get good candidates and people that want to come UK'*.

Further solutions proposed for recruitment and retention applied to both UK and international radiology staff. Recruitment events that had been taking place for a number of years that targeted radiography students completing their training were considered to be successful . Other measures cited were ensuring staff wellbeing, valuing staff, and providing the facilities to support them, building leadership, staff rotating to CDCs, offering career progression, proving CPD opportunities for both radiographer and radiologists, paid study days, family friendly policies, part-time working, and other forms of flexibility. One suggestion focused on career development in management roles:

> *'The best way to retain staff is to have some sort of career progression and I think as consultants or as medics we have that and you have a lot of autonomy as a consultant and then there's so many different roles that you can go into. And I see from the radiography side of things, and absolutely forgive me if I'm speaking wrongly, but it seems to me that you either do clinical and then if you want to go to management, you almost separate off, but there's no real career progression. So, I'm a big fan of it and would like to encourage it and I don't see that radiologists really threatened by it'.*

Challenges with retention were associated with accessing training and development opportunities for the more established workforce. An example given was that due to high service demands, together with issues of how work was prioritised, training and education tended to be neglected. Interviewees stressed the need to support training and development as a key retention strategy. The retire and return scheme, although having some constraints, meant experienced radiology staff, for example, were able to pass their skills onto new staff and educators were able to, *'get more people through the training programmes because we've got extra resources focusing on those students and enabling their training'*. One respondent suggested not only asking staff about their career aspirations regularly, but also taking action to help them meet their aspirations: *'there's a lot of 'what feels like lip service being paid to things like professional development and stuff like that'*. Radiographers found involving new staff in recruitment was helpful as they were enthusiastic and keen to recruit from schools and careers fairs and attract other people into the profession. Other measures suggested were job coaching, robust appraisal, job planning, modernizing HR, the creation of an on-call system of radiographers, Trusts being aware of vacancies in other areas and sharing potential candidates, developing a team culture that was inclusive and compassionate, and apprenticeships and other degrees that offer wider entry access. Ensuring work was interesting and people can use their skills was also cited. One interviewee noted: '*if you're going to train somebody to do these things you've got to be prepared to make it attractive beyond just giving the experience- got to make interesting jobs, with extra skills that they've learned that's what will help keep some'*.

5.4 Collaboration

Collaboration was identified as a theme and discussed in terms of how this would help deliver radiology services and support the current and future workforce. The role of public and private organisations was discussed as an issue.

5.4.1 Public and private organizations

A range of organisations are involved in collaborative working and delivering diagnostic cancer services and those discussed by respondents included the Yorkshire Imaging Collaborative, Imaging academies, CDCs, community settings, universities, and the private sector. Examples of collaborative working included sharing images, cross-Trust reporting, picking up reporting from other networks, collaboration between Trusts and community services, sharing staff and equipment. One respondent gave an example of the NHS and a private company working together and explained: '*I think once you know each other it's okay, but there were a lot of teething problems*'. There was some concern that the private sector only wanted the lucrative parts of the diagnostic services (N=3) and that any partnership arrangements needed to ensure the NHS retained control:

> *'The private sector. They'll only do something if they can make money out of it. So, they want the, what's it called, the stack-it-high, sell-it-cheap, don't they? The only way that we can compete with… because we can't compete on pay and terms and things usually. Some, independent sector organisations are all about offering cars and all sorts of things, incentives. But what we can do is offer to develop people in their professional practice. The danger always is for me […] we're going to train up four sonographers to do biopsies, you do that, and then will they go off and sell their skills to the highest bidder?'*

One interviewee felt that long-term radiology services would eventually move to an outsourced model and into community-based centres which would be privatised, with implications for staff. They noted: '*No one would want to be the last guy in the hospital, you just wouldn't want to be'***.**

The role of Imaging Academies was described in terms of, '*providing support and bringing together different groups'.* An interviewee explained that '*imaging networks are key to supporting things and bring opportunities to do things differently and look at wider capacity, so looking across the whole network, rather than within a particular Trust'*. The role of Imaging Academies was discussed in terms of them understanding what was going on where, what people were needed and service developments to '*look at ways we can deliver services that will be very different to what we've done in the past.* Imaging Academies needed to look at whole workforce planning, as opposed to regional plans, and promote working and reporting across regions, not in a single hospital setting. In addition, Imaging Academies have a role in offering CPD to staff, utilising virtual learning, examining the impact of sharing best practice, changing protocols, clinical pathways, learning from each other and sharing skills. Imaging Academies were described as providing clinical placements and helping to ensure a *'consistent approach to clinical education, alongside academic study, in a multi-professional setting'.*

In terms of collaborative working, universities needed '*to talk to each other'* and move from competition to collaboration and that NHS organisations '*very much now expected universities to collaborate'* and work in partnership with HEE and academies. An example given was the collaboration between universities and academies in the training of radiography students could make a big difference to services. Collaborative working between different organisations was seen as driving changes to increase the workforce gap and included recognition of prior learning or experiential learning, assessment by practice educators, accreditation schemes working towards an award. Another initiative described was 'sharing staff' this would be based on a digital passport linked to an individual's HR file that showed training and job opportunities.

5.4.2 Summary

Respondents suggested a range of solutions to address the gap between the required and projected radiology workforce and to help meet cancer targets. Solutions offered included the development of new and emerging roles, upskilling staff, the broadening of the scope of practice [where appropriate] and making jobs more interesting and varied, offering career opportunities and development to all grades of staff were considered as assisting in meeting radiology workforce shortages, but also helped to recruit and retain staff. Specific roles were mentioned such as enhanced, advanced and consultant radiographer roles, assistant practitioners, apprentices, practice educators, navigator roles and a 'new supervisor role' to oversee radiology services. Radiologists' roles were discussed in terms of radiology services being a consultant-led service. Recruitment and retention for UK-based and international staff was another theme that discussed as a solution to the radiology workforce shortages.

Several different organisations were seen as potentially transforming radiology services in terms of where and how diagnostic services would be delivered but it was highlighted that they needed to work collaboratively. The benefits of Community Diagnostic Centres focused on the delivery of non-acute work and primary diagnostics out of the acute setting, with CDCs supporting training for all radiology staff and providing good working environments. Similarly, Imaging Academies was regarded as playing a key role in providing opportunities to do things differently and look at the wider radiology workforce capacity across a network.

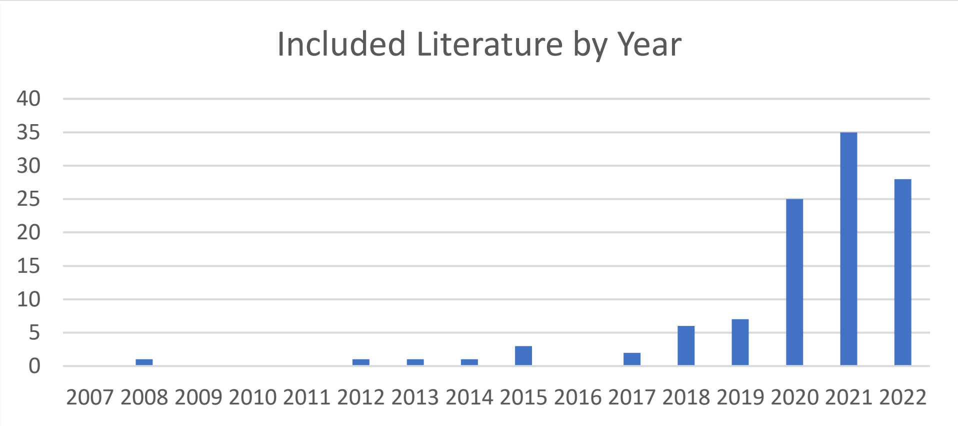
5.5 Artificial intelligence

During the interviews respondents talked about using AI to address cancer targets (see section 4.11 above). Recognising the importance of this area, we carried out a rapid literature review to explore, in more detail, the use of AI in radiology and its impacts on workload. Below, we present the findings of this review before setting out respondents' perspectives on AI as a possible solution.

5.5.1 Overview of included literature

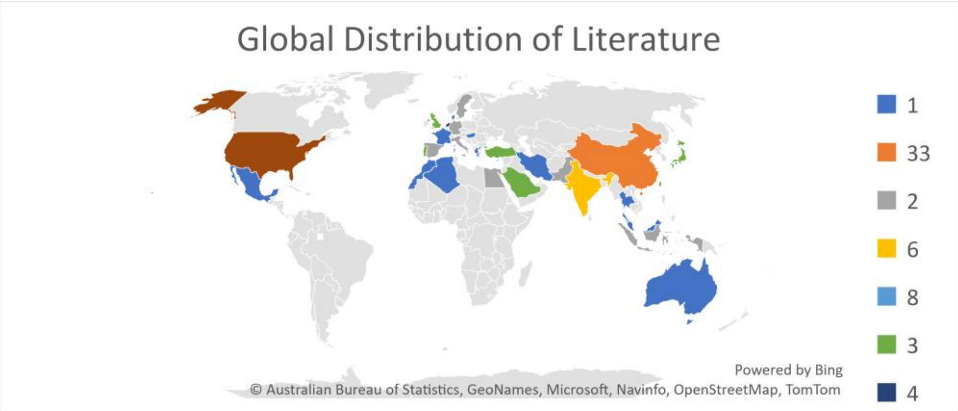
Results of the quality appraisal undertaken of each item of included literature are presented in Appendix 4, whilst Appendix 5 includes a summary in tabular format of the included literature. Overall, 734 records were retrieved from searching five databases. Following deduplication, 476 records were screened by title/abstract with 185 reports sought for full text screening. This review includes 110 studies. No policy documents were retrieved.

Figure 16: Included literature by year



Most literature included within the review was published in 2021 (n = 35) with a noticeable increase in publications from 2020 onwards. Figure 16 illustrates included literature of the review by year.

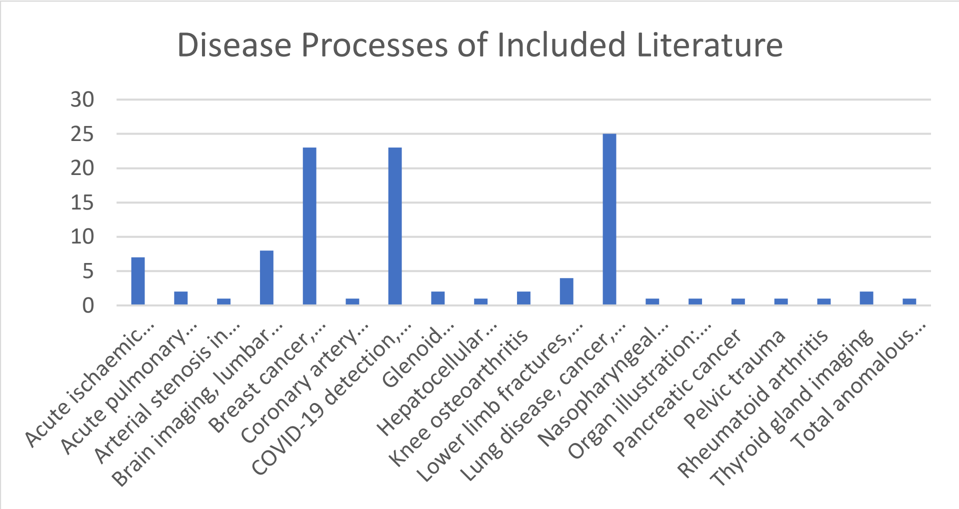
Figure 17: Global Distribution of Literature



The included literature is international, illustrated on the map. Most literature is from researchers in China (n = 33), followed by 13 items from researchers in the United States (US), eight items from international research collaborations and six from researchers based in India. It is worth noting all research involved AI development and/or evaluation, with the impacts for workload/workflow noted as secondary outcomes. Researchers often relied on or incorporated publicly available datasets to develop and evaluate AI, for example those identified in the work of Agrawal and Choudhary (2022) including Imagenet; Japanese Society of Radiological Technology database; from Shenzhen No. 3

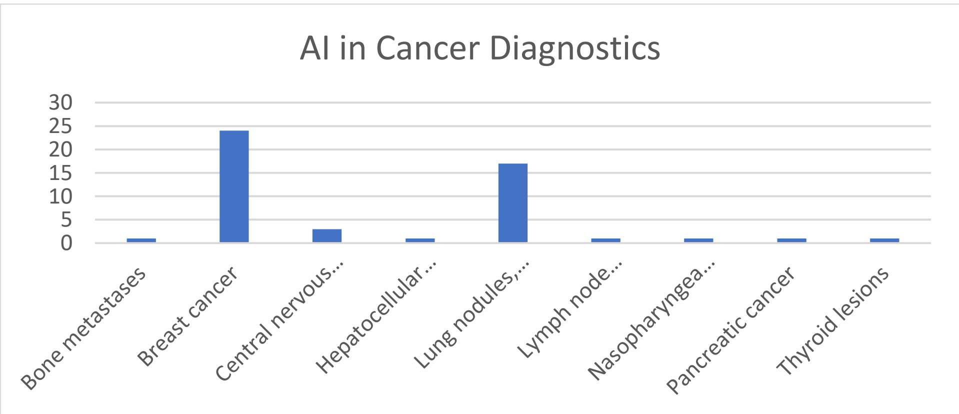
People's Hospital in China; Department of Health and Human Services Montgomery County, Maryland; National Institutes of Health Chest X-ray Dataset. Similarly, Alduraibi (2022) utilised the Breast Ultrasound Images Dataset. Hidayah et al. (2015) used the University of California Irvine Machine Learning Repository. The Lung Image Database Consortium (LIDC-IDRI) was used in the work of Ismaeil and Salem (2020); Kasinathan and Jayakumar (2022); Monkam et al. (2018); Seidel et al. (2015); Tandungan et al. (2019) and Zamacona et al. (2015).

Figure 18: Disease Process of Included Literature



A range of disease processes are illustrated within the included literature (Figure 18). AI associated with diagnostics with lung and chest disease most frequently occur, with n= 25. Twenty-three items of literature examine AI for COVID-19 diagnosis and pneumonia secondary to COVID-19. Similarly, 23 items of literature present AI for breast screening; pathologies including cancer. AI application in imaging of the central nervous system is illustrated in eight items and seven items focus on acute ischaemic stroke, haemorrhage infarction and intracranial aneurysms.

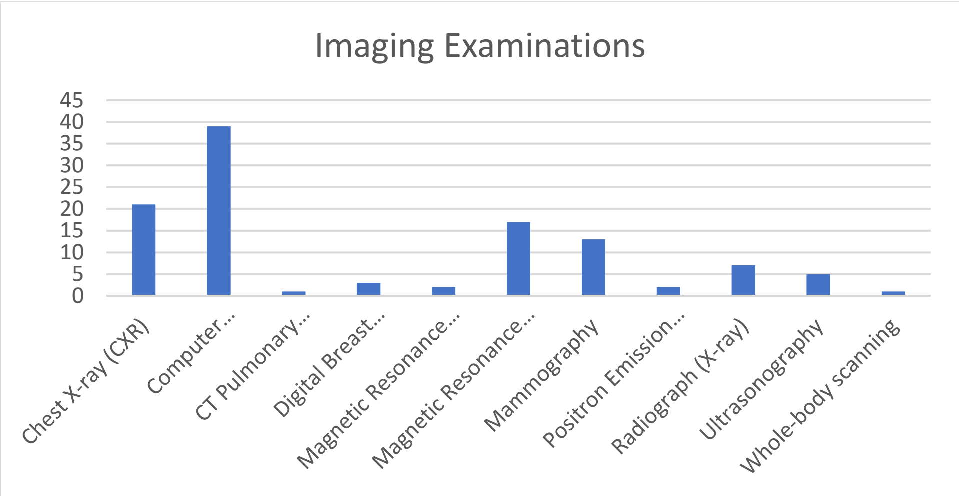
Figure 19: AI in Cancer Diagnosis



Notably AI in cancer diagnostics is apparent in 50 studies, with most concerned with breast cancer (n = 24), lung nodules, disease including cancer (n = 17) and cancers of the central nervous system (n = 3). The full illustration of AI for cancer diagnostics is presented in Figure 19.

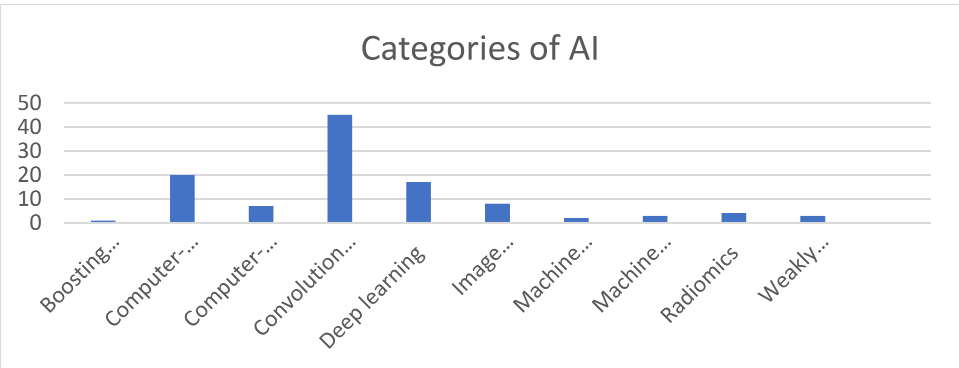
All literature, except one item, references the impacts of AI for the workload/workflow of medics by using the terms ‘doctors’, ‘radiologists’, ‘physicians’ and ‘medical practitioners.’ Pedrosa et al. (2022) reference the impact of AI for ‘technicians’ and ‘radiologists.’ On occasion medical specialities are referenced, for example ‘nuclear medicine physicians’ (Hsieh et al. 2021) and ‘neuroradiologists’ (Kakeda et al. 2008).

Figure 20: Imaging Examinations



The range of imaging examinations illustrated by the literature is presented in Figure 20. Computed Tomography (CT) is the most common imaging examination utilised for AI development and evaluation (n = 39). Radiographs are also used extensively with most radiographs as chest X-rays (n = 21). Magnetic Resonance Imaging (MRI) and Magnetic Resonance Angiography (MRA) are referenced as the basis for AI development and evaluation in 19 studies. Mammography was the imaging examination of choice in 13 studies.

Figure 21: Categories of AI



Categories of AI illustrated within the literature are shown in Figure 21. These categories are selected as ‘best-fit’ for the AI described in each item of literature. The most commonly described AI category is convolutional neural networks (CNNs) (n = 45). There is variation in how authors describe the CNN in their research, for example Amara et al. (2022) present a ‘novel neural network architecture’, Hsieh et al. (2021) describe ‘convolutional neural network-based (CNN-based), residual neural network (ResNet), and densely connected convolutional networks (DenseNet) models’ and Jiao et al. (2020) present a ‘deep convolutional neural networks-based’ model. Ma et al. (2022) present a ‘densely connected convolutional network’ and Noshad et al. (2021) present a ‘deep residual neural network’. Deep learning is also frequently referenced (n = 17) in the literature in relation to neural networks to describe multi-tiered AI capable of learning from data inputs for image interpretation.

Computer-aided diagnosis/detection (CAD) including image segmentation is represented as a common application (n = 27) in the literature, often from CNNs. CAD is used for disease detection and in disease classification for diagnosis often coupled with image segmentation (n=7). Automating image segmentation with, for example, weakly supervised CAD would aid physician workload reduction considerably (Cao et al. 2022; Chen et al. 2021b). The contribution of AI to automate segmentation is further discussed in the next section. Machine learning is referenced in a small number of studies (n = 5) and is largely considered an antiquated term (Alajmi et al. 2022). Radiomics is also referenced in a small number of studies (n = 4), benefitting quantifiable data interpretation notably in the diagnosis of lung nodules (Ma et al. 2017), pancreatic cancer detection and/or classification (Qiu et al. 2018) and glioma grading (Zhao et al. 2022).

5.5.2 Artificial intelligence for reducing volume of workload

Percentage estimates for reductions in clinical radiologists’ workload owing to AI implementation are variable. Dyer et al. (2021) report their deep learning algorithm is able to reduce total chest X-rays (the most common radiological examination it the UK NHS) for radiologist review by 15%. In a later study by Dyer et al. (2022: 742) AI for differentiating ‘normal’ from ‘abnormal’ head CTs achieved a reduction in 27.4% scans for the’ average’ radiologist. Jing et al. (2022) report on AI in reading breast MRIs differentiating by positive/negative predictive value (P/NPV), and a workload reduction of 15.7%, with a minimum scan time reduction of 16.6%. The greatest estimates of percentage reductions in clinical radiologists’ workload are seen in the context of national screening programmes. For example, Lancaster et al. (2022) report on an AI prototype in ultra-low-dose CT as ‘a standalone reader’ for lung nodule diagnostics, at screening stage, noting radiologists’ workload may be reduced by up to 86.7%. Lauritzen et al.’s (2022) evaluation of an AI system in the context of national mammography screening in Denmark advise of a potential radiologist workload reduction of 62.5%. Raya-Povedano et al. (2021) report similarly on utilising an AI system within a Spanish breast screening context with a workload reduction of 70% for radiologists. Yala et al.’s (2019) evaluation of AI incorporated to triage screening mammograms notes a 19.3% reduction in radiologists’ workload.

AI has the potential to automate fully initial steps in radiology diagnostics notably through differentiating imaging examinations by those ‘with’ from those ‘without’ disease; termed computer-aided detection or diagnosis. For example, Abbas et al. (2020) have designed a Faster R-CNN deep learning model to detect without clinician input, fractures on the X-rays of lower leg bones with the benefit of radiologists gaining more time for patient interaction and a reduced workload. AI, particularly utilising convolutional neural networks, for the automated detection of COVID-19 on chest X-rays for rapid disease identification is reported widely (Alajmi et al. 2022; Allaouzi et al. 2021; Hussain and Ruza 2022; Joshi et al. 2021; Keidar et al. 2021; Noshad et al. 2021). Similarly, Ragab and Attallah (2020) designed an AI tool for automated COVID-19 detection using CT scans. Automated detection of ‘normal’ from ‘abnormal’ mammograms is analysed in the work of Dembrower et al. (2020: e473) for a ‘no radiologist triage’ system.

One of the most significant means by which AI positively impacts radiology workload is automation in segmentation with numerous references (n > 20). Segmentation is a process for image analysis, often coupled with classification, where segmentation owing to image sub-division leads to refined tissue contouring, and classification aids image level disease prediction based on image data (Agrawal and Choudhary 2022). Convolutional neural networking is utilised commonly for AI-driven automation in segmentation (Amara et al. 2022; Cunha et al. 2020; Gaal et al. 2020; Ghosal et al. 2021; Jiao et al. 2020; Khaled et al. 2021; Li et al. 2020; Luo et al. 2022; Mahmood et al. 2021; Qi et al. 2021; Rajaraman et al. 2021; Sichtermann et al. 2019; Van der Oever et al. 2020; Zhang and Zhang 2021). Particularly, interest is shown in the use of AI to automate lung segmentation in the detection and/or diagnosis of COVID-19 (Aiello et al. 2022; Amara et al. 2022; Zhang and Zhang 2021), lung disease (Ali et al. 2020; Rajaraman et al. 2021) and lung nodules (Gaal et al. 2020). Similar interest is also evident in AI for automation in segmentation of known or suspected malignancy for example in the analysis of images of breast lesions (Antonios et al. 2013; Jiao et al. 2020; Khaled et al. 2021), hepatocellular carcinoma (Cunha et al. 2020) and nasopharyngeal carcinoma (Qi et al. 2021). Sichtermann et al.'s (2019) AI to automate segmentation of intracranial aneurysms offers the potential of automation in segmentation to reduce radiologists' cognitive strain. Van der Oever et al.'s (2020) AI for detection of coronary artery calcium (CAC) exclusion or segmentation benefits a reduction in 86% of all scans for CAC requiring radiologist review.

5.5.3 AI for improving efficiency of radiology workflow

AI may also contribute to radiology workload efficiency by acting as a tool for supplementary diagnosis. Chen et al. (2021a: 231) evaluate deep transfer learning, for rapid detection and classification for COVID-19, claiming improved sensitivity and reduced reading time versus manual reading, concluding transfer learning as a model for 'auxiliary diagnosis'. Similarly multiple researchers term AI as a tool for 'second opinion'. Ali et al. (2020) advise AI proffering second opinion increases objectivity in diagnosis. Galvan-Tejada et al. (2017) note AI for second opinion supports classification of breast tumours. Hussain et al. (2022) advise their AI gave radiologists a second opinion during interpretation to aid COVID-19 diagnosis. Noshad et al. (2021) note that AI provide a second opinion may not only decrease workload but also improve accuracy in COVID-19 detection. Pedrosa et al.'s (2022: 15) research presents a more sceptical view of deep learning performances for COVID-19 screening, but nonetheless concludes that AI could provide a 'robust' second opinion. Rao et al.'s (2021: 92) recommendation from their research utilising AI in the context of intracranial haemorrhage diagnosis is 'as an adjunct to current peer review tools as a second reader …'. Wang et al.'s (2021) work also in relation to intracranial haemorrhage (detection and classification) proposed AI for second reading or triage as workflow facilitation. AI for supplementary diagnosis or 'second opinion' may streamline interpretation and thus reduce the number of clinicians to read and report. McKinney et al. (2020: 93) note AI for breast cancer screening has the potential to reduce 'the need for double reading in 88% of UK screening cases …' with no loss of accuracy.

AI has been found to reduce the time taken to read individual scans. Benedikt et al. (2018) conclude their computer-aided detection system with digital breast tomosynthesis is capable of reducing reading time by 29.2%. Joshi et al. (2021) contend their AI is capable of detecting COVID-19, from non-COVID-19, on chest X-rays in 0.137 seconds. Li et al. (2020) claim their AI for automatic segmentation of imaging in total anomalous pulmonary venous connection results in 400 milliseconds compared with two to three hours by manual segmentation. Improved rapidity of disease detection or diagnosis may expedite patient management, notably treatment, particularly in urgent cases but may also improve communication between clinicians. For example, Meng et al. (2019) report AI for timely communication between radiologists and referring physicians.

AI has the potential to support less experienced radiologists as an adjunctive diagnostic tool. Kakeda et al. (2008) note that AI can improve accuracy in the reading of MR angiography for intracranial haemorrhage by less experienced radiologists. In addition, those less experienced radiologists assisted by a computer-aided diagnosis system (CADS) were quicker in their reading than experienced neuroradiologists without CADS. Yao et al. (2021) in the context of rib fracture detection also conclude AI aids clinician reporting performance including speed of diagnosis for both junior and experienced radiologists.

Efficiency of triage, the process by which image/patient management may be ordered, can be aided by AI application. For illustration, the work of Galvan-Tejada et al. (2017: 14) advise their AI 'may have the practical use of triaging mammograms in developing countries where there is a deficiency of expert readers.' Rodriguez-Ruiz et al. (2019: 4830) propose AI 'to automatically pre-select exams for radiologist evaluation …'. Verburg et al. (2022) and Yala et al. (2019) similarly propose AI for automated triaging breast screening, notably for benefit where double reading by clinicians is standardised practice (in Europe) to aid clinical efficiency; AI plus clinician compared with two clinicians. Rajaraman et al.'s (2021: 28) AI for tuberculosis classification proffers 'advanced assistance in radiologist interpretive workflows to include triage of abnormal findings …'. Zapaishchykova et al. (2021: 424) propose AI, based on classification, for 'an automated yet interpretable pelvic trauma decision support system'. AI to support clinical decision-making support is also examined by Zamacona et al. (2015), utilising classification for diagnostic categorisation and determination of subsequent radiologist reading requirement. Grauhan et al. (2022: 355) promote AI for worklist prioritisation and 'safety in situations of increased workload.'

AI may aid improved sensitivity and specificity in delineating areas of suspicion, notably suspected malignancy. Antonios et al. (2013) describe BreDAn to automate detection, differentiation and staging of breast lesions. Chang et al. (2022: 1) conclude their AI was capable of 'reliable quantitative lung diagnosis …'. AI can also benefit improved sensitivity in the detection of small, asymptomatic, vascular lesions. For example, Cao et al. (2022: 1) report on AI to detect acute ischaemic stroke and haemorrhagic infarction lesions finding AI 'had significantly greater patient-level sensitivity than did the human readers.'

Increasingly AI becomes shared knowledge for international implementation, and available for commercial distribution. For example, both Johansson et al. (2021) and Lauritzen et al. (2022) evaluate the application of Transpara® as a computer-aided detection/diagnosis system in mammography. Aiello et al. (2022) evaluated a range of AI-based segmentation tools for the diagnosis of COVID-19. Similarly, Ardakani et al. (2022) appraised 10 convolutional neural networks for the management of COVID-19 diagnosis. Applications of ResNet, a residual neural network which can be used for image classification, are referenced in the work of Grauhan et al. (2022); Hseih et al. (2021); Jacob et al. (2021) and Zhang and Zhang (2021). U-Net, a convolutional neural network for image segmentation is referenced in the work Gaal et al. (2020); Khaled et al. (2022); Liu et al. (2020); Mahmood et al. (2021); Rajaraman et al. (2021); Zhang and Zhang (2021).

5.7 Summary

The rapid review helped to identify benefits with AI, although there are some caveats. It found that AI can reduce the volume of radiology services' workload, but this is dependent on the nature of the work and the AI function. As a result of faster AI reading, radiologists may be able to focus on high-risk, complex reading tasks. AI can support automation of image segmentation and classification and thus aid the diagnostic confidence of less experienced radiologists and it can contribute to improved workflow efficacy and efficiency of radiology services.

6. Summary and implications

The overall findings of the deep dive provide insights into the delivery of diagnostic cancer radiology services for West Yorkshire and the radiologist and radiography workforce. The deep dive explored three questions, which will now be considered.

6.1 What is the current and projected demand for radiology services?

Overall, the findings show that demand for radiology services is increasing and that both cancer waiting times and the waiting times for diagnostic tests increased, with a concurrent downward trend in activity that, if all else stays the same, is forecast to continue up to 2025. The cancer waiting times data indicate that patients were waiting longer and that their needs were not being met. Moreover, the proportion of people treated within accepted cancer waiting times decreased both nationally and within the West Yorkshire region from 2013. This was exacerbated by COVID-19 which caused a further decrease nationally and for the West Yorkshire region.

National data for waiting times for all diagnostic tests show a significant decline between 2006 and 2008, with a decrease in median waiting times from just under 6.0 weeks to approximately 2.0 weeks. Overall, waiting times remained stable until late 2020 when they started to rise with the longest median waiting times at just over 8.0 weeks in mid-2020. The total number of people waiting for radiology tests nationally is decreasing and is predicted to continue to do so, while in West Yorkshire the number of people waiting for radiology tests decreased until 2020 but has since been on an upward trend which is predicted to continue. Nationally, the total number of radiology tests is on an upward trend that is predicted to continue, while in West Yorkshire activity has been decreasing since well before COVID-19 and is predicted to continue to do so.

These findings suggest that, despite the targets set by NHS England and NHS Improvement (2022) in the Delivery plan for tackling the COVID-19 backlog of elective care, demand for radiology services in West Yorkshire continues to increase and will for the foreseeable future. An inability to meet cancer targets both nationally and in West Yorkshire had been an issue for some years prior to COVID-19, which heightened the demand and unmet needs of patients requiring healthcare, notably cancer care diagnostics. While, based on the data presented, it is not possible to predict the number of radiologists and radiographers required to meet demand, it does suggest that the current workforce is not sufficient and, if all else remains the same, the numbers required to meet demand will continue to increase.

6.2 What is the current and projected radiology workforce in West Yorkshire?

Data examining the current and future workforce showed that the national figures for the total radiology and radiography workforce are small relative to other health professional groups. In West Yorkshire, 265 radiologists and 926 radiographers were employed, and staff turnover was generally low. Trusts' forecasts for the number of radiologists and radiographers they believe they need suggest a 16% increase in the number of radiologists in post between March 2022 and March 2027 and a 25% increase in the number of radiographers in post. The numbers of radiographers and radiologists being trained in West Yorkshire suggest that this is feasible.

Interview data identified a number of main themes and associated issues: delivering diagnostic cancer targets, strategic workforce planning, workforce roles and skills, service transformation, recruitment and retention, universities, artificial intelligence, collaboration, and international recruitment. Across all themes, some reoccurring issues were identified: a lack of staff, increased demands, a lack of capacity in terms of space and staff, a lack of strategic workforce planning with a focus on operational or financial plans.

6.3 What possible solutions are there for addressing the gap between the required radiology workforce and the projected radiology workforce?

A range of solutions was offered to address workforce challenges: more apprenticeship schemes, vocational options, a Skills Escalator to assist with career progression, and the provision of support to all staff through the Leadership Academy. The use of Practice Educators to support students and current staff was recommended, along with a greater role for consultant radiographers in the development and training of trainee radiologists. The opportunity to develop administrators or assistant practitioners to undertake Navigator roles and for physician's associates, working under radiologists' supervision, were also mentioned. Furthermore, due to the expansion of CT scanners, a new supervisor role was suggested, which would oversee radiology services in areas such as A&E. Artificial Intelligence was seen as having the potential to transform the work of radiographers into 'healthcare scientists,' supported by an assistant practitioner workforce. In a similar vein, several different organisations were regarded as having the potential to transform radiology services in terms of where and how diagnostic services would be delivered and in helping to bridge the gap between the current and future workforce. However, they needed to work collaboratively. The benefits of Community Diagnostic Centres were seen in the delivery of non-acute work and primary diagnostics, supporting training for all radiology staff and providing a better working environment. The need for NHS Trusts, universities and other organisations to work collaboratively, in partnership and in a planned way was stressed. It was anticipated that this approach would avoid the possibility of equipment located in CDCs not being fully utilised or competition occurring between CDCs and Trusts for radiology staff. A proposal suggested was that CDCs could be used as sites to which staff from busy hospital settings could be rotated to less acute activity. It was anticipated that this would assist with maintaining staff skills base and quality and would support upskilling, as well as helping to retain staff, offer job variation, and develop skills.

Another way to address cancer targets was the use of AI. Our rapid review of the literature on AI in radiology and its impacts on workload identified that AI can reduce the volume of radiology services workload, but this is dependent on the nature of the work and the AI function. A reduction in the volume of images radiologists are reading may ameliorate fatigue and enable clinicians to focus on high-risk, complex reading tasks, benefitting not only clinician accuracy but also improved patient experience. AI can also aid the diagnostic confidence of less experienced radiologists, improving both their accuracy and speed. AI may also contribute to radiology workload efficiency by acting as a tool for supplementary diagnosis in terms of AI as a tool for 'second opinion'. AI has been found to reduce the time taken to read individual scans.

6.4 Implications

Based on the presented data, we consider that there are a number of implications, including suggestions of the role that the ICS could play in ensuring adequate staffing of diagnostic radiology services:

1. There is a need for joined up workforce planning for radiology services, where decisions about staffing are linked with decisions around the purchasing of equipment and where the impact for radiology of recruitment in other roles (e.g. surgery) is considered;
2. Given the importance of collaboration between radiologists and radiographers, opportunities for interprofessional learning should be identified/developed;
3. Recruitment for radiology roles should be at ICS level, allowing staff to be appointed to where need is greatest;
4. There is a need for ICS level agreement around responsibilities for assistant practitioners and support workers in radiology, ensuring consistency across the ICS;
5. A collaborative approach amongst Trusts to staffing of CDCs should be taken, to avoid Trusts losing staff to CDCs;
6. While AI may have to address workforce challenges, there is a need for training and clarity regarding responsibility.

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Appendix 1: Participant Information Leaflet

Workforce Observatory for West Yorkshire ICS:
Planning the Radiology Workforce
Participant Information Leaflet

Hello,
We are inviting you to take part in the study detailed below. Before you decide whether to accept, we would like to explain why the study is being undertaken and what it will involve. Please read this information carefully, and ask if anything is unclear, or if you would like more information.
Part 1 tells you the purpose of this study and what will happen to you if you take part.
Part 2 gives you more detailed information about the conduct of the study.
Thank you for taking the time to read the following.

PART 1

What is the purpose of the study?

An essential part of workforce planning is ensuring we have the right radiology and radiography workforce both now and for the future. The aim of this study is to understand the current/projected radiology and radiography workforce in West Yorkshire. For this reason, we are undertaking interviews to find out about changes that may influence the workforce. The aim is to use the findings from the study to feed into West Yorkshire ICS's strategic workforce planning.

Why have I been invited?

You have been chosen to take part because we are interested in talking to radiology service managers, those involved in training radiologists and radiographers, and others who are involved in planning radiology services.

Do I have to take part?

- No. It is up to you to decide whether or not to take part in this study.
- If you do decide to take part, you are still free to withdraw without giving a reason. You can withdraw up until 48 hours after the interview has taken place.

What will be involved if I agree to take part?

If you decide to take part, a member of the research team will arrange a time that is convenient for you to take part in the interview. The interview will take place over the telephone or via videocall (whichever you prefer). The interview will take no more than an hour and will be audio recorded.

Please be assured that all collected data will be transcribed and analysed to see if there are any common themes. All data will be anonymised, removing all personal information, so that you will not be identifiable. If after the interview you change your mind about participating, you can choose for the audio recording and transcript to be destroyed or returned to you immediately.

Are there any risks?

We do not think that there are any risks to you in taking part in the study.

This completes Part 1.

If the information in Part 1 has interested you and you are considering participation, please read the additional information in Part 2 before making any decision.

PART 2

Will my taking part in this study be kept confidential?

Yes. All data will be treated in confidence. Participants in the study will not be identified by name in any publications. Quotations may be used in publications, but all personal information will be removed so that it is not possible to identify you. All information will be safely stored at the University of Bradford for five years from the completion of the study, after which it will be disposed of securely.

All information collected will be handled, processed, stored, and destroyed in accordance with the Data Protection Act 2018. Where personal data is provided this will be stored separately to study data and held on the University of Bradford secure IT system which has restricted password protected access for the research team working directly on the study. Audio recordings of interviews will be transferred to the secure network and once transferred, recordings will be erased from the recording device. The audio recordings of interviews will be transcribed by a third-party transcription company following completion of a Non-Disclosure Agreement and data transfer to a secure, Data Protection Act compliant system.

The University of Bradford is the sponsor for this study based in the United Kingdom. We will be using information from you in order to undertake this study and will act as the data controller for this study. This means that we are responsible for looking after your information and using it properly. The University of Bradford will keep identifiable information about you for the purpose of the study for up to 12 months after the study has finished.

Your rights to access, change, or move your information are limited, as we need to manage your information in specific ways in order for the study to be reliable and accurate. To safeguard your rights, we will use the minimum personally identifiable information possible.

The University of Bradford will use your name and contact details to contact you about the study, and make sure that relevant information about the study is recorded, and to oversee the quality of the study. Individuals from the University of Bradford may look at study records to check the accuracy of the study. The only people in the University of Bradford who will have access to information that identifies you will be people who need to contact you or audit the data collection process.

You can find out more about how we use your information by contacting Professor Rebecca Randell using the details at the end of this leaflet.

Who is organising and sponsoring the study?

The sponsor is the University of Bradford, and they take on ultimate responsibility for securing the arrangements to initiate and manage this study. Ethics approval has been granted by the Chair of the Humanities, Social and Health Sciences Research Ethics Panel at the University of Bradford on (Ref:EC27051)

What if there is a problem?

If you have a concern about any aspect of this study, please contact Professor Rebecca Randell on 01274 234144 or r.randell@bradford.ac.uk.

What do I do now?

Once you have read the information and if you would like to take part in the study or would like further information, please email Professor Rebecca Randell using the details at the end of this leaflet. Someone from the research team will contact you to answer any questions and arrange a time for the interview.

Further information and contact detail

Thank you for taking the time to read this leaflet and for considering this study. If you would like to discuss the study further or have any questions about the study at any time, please contact Dr Julie Prowse on 01274236374 or J.Prowse@bradford.ac.uk

Appendix 2 Interview Topic Guide for Interviews

Start of interview

Thank respondent for agreeing to participate

Explain the interview is for an hour (if possible) voluntary, confidential, anonymous

Interview is, recorded and transcribed

Explain the purpose of the research and a bit of background

This project is looking at the radiology service and the workforce across the West Yorkshire and Harrogate (WY&H) Integrated Care System (ICS) and is part of wider ongoing collaborative work with the WY&H Cancer Alliance, Yorkshire Imaging Collaborative, and West Yorkshire Association of Acute Trusts (WYAAT) focusing on the role of radiology in cancer diagnosis and reviewing the current and future radiology workforce.

The project team are based at the University of Bradford and are also part of the Workforce Observatory, whose role is to undertake strategic workforce planning, using evidence/research-based findings to help plan strategic workforce planning. The findings from this interview will feed into the WO planning.

As a summary, an essential part of workforce planning is ensuring we have the right radiology and radiography workforce both now and for the future. The aim of this study is to focus on the role of radiology in cancer diagnosis and understand the current/projected radiology and radiography workforce in West Yorkshire, the approaches used for strategically planning the workforce, development of new roles, alternative ways of working, any proposed workforce changes and transformations and any collaborative work being undertaken.

Can we have your permission to record the interviews and to assure you of the confidentiality'

End of interview thank interviewee and ask if there are any other queries/questions they may have.

Interview questions: Radiology Service Managers

General (do quickly)

1. Can you please tell me what your role is and briefly describe your service? (Does it involve cancer diagnosis?)
2. Can you briefly tell me about your current workforce (numbers, roles, any issues?)

Strategic Workforce planning

3. Can you tell me how strategic workforce planning is undertaken in your service?
4. Do you think long term, there are challenges in ensuring radiology services have the right workforce? What are those challenges? short term issues? (Sickness, older workforce, shortages)
5. In terms of achieving the timely cancer diagnosis targets/service delivery. What do you think are the workforce issues? What is needed for your service? (For the future and now)

Workforce changes/transformations

6. Please can you tell me about any radiology service workforce change/transformation projects you are currently/or want to undertake. (Ask for examples).
7. What do you think may be some of the problems with the radiology service workforce change/transformation projects? (Ask specifically about the examples they mention) Potential solutions?
8. Can you give any examples of collaborating or intending to collaboration with other trusts, private hospitals, organisations in the provision of radiology services for cancer diagnostics? Can you see opportunities for greater collaboration? Locally/regionally/nationally?
9. We know some Trusts are thinking about using artificial intelligence within radiology. What do you think of this? Is this something you're considering? What do you think the implications are in terms of workforce? Potential challenges and solutions?

Workforce Roles

1. What are your thoughts about international recruitment and outsourcing services to support the achievement of timely cancer diagnosis/service delivery?
2. How do you think that alternative ways of working, upskilling, and new roles could support the achievement of timely cancer diagnosis? Examples of specific roles?

Any other comments?

UNIVERSITY of BRADFORD

West Yorkshire
Health and Care Partnership

Interview Questions: Academics at Yorkshire Universities

General (keep it brief)

1. Can you please tell me what your academic role is?
2. If involved in programme delivery: can you briefly describe the programmes?
3. Can you briefly tell me about current radiography student numbers (Any issues? Recruiting and retaining students/employability post course?)

Strategic Planning

4. Do you think long term, there are challenges in ensuring radiology services have strategically planned for the right workforce? What are those challenges? Do universities have a role in this? (Sickness, older workforce, shortages)
5. In terms of achieving the timely cancer diagnosis targets/service delivery, what do you think are the workforce issues? What are the implications for universities? (For the future and now)

Workforce Roles

6. As an academic, how do you anticipate the future radiology /radiography workforce roles changing? How do you think universities/institutions are/should be responding? (Please illustrate this with specific roles)
7. What are your thoughts about international recruitment and outsourcing services to support the achievement of timely cancer diagnosis/service delivery?
8. In what ways do you think alternative ways of working, upskilling and new roles may benefit future radiology/radiography workforces? Help with the delivery of efficient, timely, cancer diagnoses? Examples of specific roles?

Education and Service changes/transformation

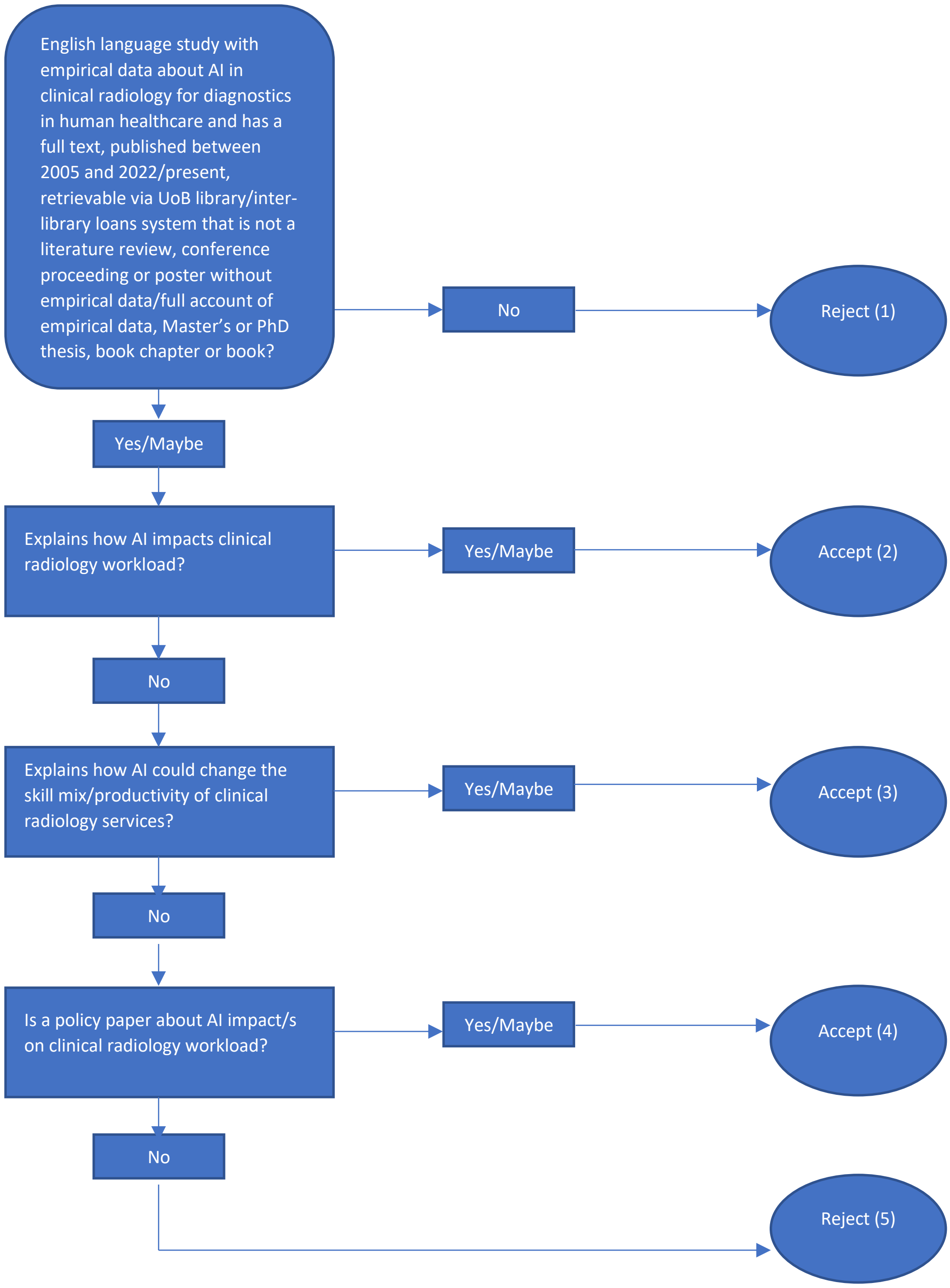
9. Can you tell me what you think are the key workforce change/ transformation projects that are strategically transforming radiology/radiographer services and the implications for universities E&D?
10. What do you think may be some of the problems with the radiology service workforce change/transformation projects? Potential solutions? Implications for universities?
11. Please tell me what you think about the use of AI within radiology/radiography? What do you think is the potential for AI to support cancer diagnosis within radiology and What are the implications for university education?
12. Can you think of any other educational strategies/approaches that could support the achievement of timely cancer diagnosis targets/service delivery?

Any other comments?

Thanks

Appendix 3: Flowchart for full text screening

Where possible the full texts of all 'included' records following title/abstract screening have been attached to the title/abstract record in an EndNote library. Where full texts are not available (from UoB library or the inter-library loan request system) for any record, the abbreviation: NA may be added to the 'Research Notes' for the record in the EndNote library; for example: 2, NA; 3, NA or 4, NA. For full texts that are not in English, the abbreviation: NE may be added into the 'Research Notes' of the EndNote library record, for example: 2, NE. Screening of available full texts may be achieved by using the following algorithm and updating the 'Research Notes' of the record in the EndNote library; for example: 2, 1.



Appendix 4 Quality appraisal of included studies using the Mixed Methods Appraisal Tool[1] (2018)

Included studies	Quantitative non-randomized					Quantitative descriptive					Mixed methods				
	3.1	**3.2**	**3.3**	**3.4**	**3.5**	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	**5.1**	**5.2**	**5.3**	**5.4**	**5.5**
Abbas et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Agrawal and Choudhary (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Aiello et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Alajmi et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Alduraibi (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Ali et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Allaouzi et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Amara et al. (2022)	Y	Y	Y	?	Y	Y	Y	Y	NA	y	-	-	-	-	-
Antonios et al. (2013)	-	-	-	-	-	Y	Y	Y	NA	y	-	-	-	-	-
Ardakani et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	y	-	-	-	-	-
Benedikt et al. (2018)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Calisto et al. (2021)	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y	Y
Cao et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Chang et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Chen et al. (2021a)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Chen et al. (2021b)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Clymer et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Cunha et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Dai et al. (2021)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Dembrower et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Duron et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-

[1] Hong, Q. N., Pluye, P., Fabregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M-P., Griffiths, F., Nicolau, B., O'Cathian, A., Rousseau, M-C., Vedel, I. (2018) *Mixed Methods Appraisal Tool (MMAT) Version 2018, User guide*. http://mixedmethodsappraisaltoolpublic.pbworks.com/w/file/fetch/127916259/MMAT_2018_criteria-manual_2018-08-01_ENG.pdf Accessed 29 July 2022

Dyer et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Dyer et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Feng et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Gaal et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Galvan-Tejada et al. (2017)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Ghosal et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Grauhan et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Hallinan et al. (2021)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Han et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Hidayah et al. (2015)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Hsieh et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Huang et al. (2019)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Hussain and Ruza (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Ismaeil and Salem (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Jacob et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Jang et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Jiao et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Jing et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Johansson et al. (2021)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Joshi et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Kakeda et al. (2008)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Kasinathan and Jayakumar (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Keidar et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Khaled et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Kim and MacKinnon (2018)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Lan and Zhong (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Lancaster et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Lauritzen et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Li et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Li et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Lin et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Liu et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-

Liu et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Loizidou et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Luo et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Ma et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Ma et al. (2017)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Mahmood et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
McKinney et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Meng et al. (2019)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Monkam et al. (2018)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Noshad et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Pan et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Parascandolo et al. (2015)	Y	Y	?	?	?	-	-	-	-	-	-	-	-	-	-
Pedrosa et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Polat et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Pongsakonpruttikul et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Postalcioglu (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Prasad et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Purkayastha et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Qi et al. (2021)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Qiu et al. (2018)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Ragab et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Rajaraman et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Rao et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Raya-Povedano et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Rodriguez-Ruiz et al. (2019)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Saba et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Salem Salamh et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Seidel et al. (2014)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Sheela and Arun (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Shibata et al. (2021)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Shimada et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Shoshan et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-

Sichtermann et al. (2019)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Siddiqui et al. (2020)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Su et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Tandungan et al. (2019)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Tsai et al. (2012)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Tsai et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Van den Oever et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Verburg et al. (2022)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Vilares et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Wang et al. (2018)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Wang et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Wong et al. (2019)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Wu et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Yala et al. (2019)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Yan et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Yang et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Yang et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Yao et al. (2021)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-
Yates et al. (2018)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Zamacona et al. (2015)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Zapaishchykova et al. (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Zhang et al. (2019)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Zhang and Zhang (2021)	-	-	-	-	-	Y	Y	Y	NA	?	-	-	-	-	-
Zhao et al. (2022)	-	-	-	-	-	Y	Y	Y	NA	Y	-	-	-	-	-
Zhou et al. (2020)	Y	Y	Y	?	Y	-	-	-	-	-	-	-	-	-	-

Notes

No studies were solely qualitative (1. of the MMAT algorithm) or randomised controlled trials (2. of the MMAT algorithm) hence these groups of screening questions have not been incorporated on the above table

- Quantitative non-randomized appraisal criteria: 3.1 Are the participants representative of the target population? 3.2 Are measurements appropriate regarding both the outcome and intervention (or exposure)? 3.3 Are there complete outcome data? 3.4 Are the confounders accounted for in the design and analysis? 3.5 During the study period, is the intervention administered (or exposure) as intended?

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- Quantitative descriptive appraisal criteria: 4.1 Is the sampling strategy relevant to address the research question? 4.2 Is the sample representative of the target population? 4.3 Are the measurements appropriate? Is the risk of nonresponse bias low? Is the statistical analysis appropriate to answer the research question?
- Mixed methods appraisal criteria: 5.1 Is there an adequate rationale for using a mixed methods design to address the research question? 5.2 Are the different components of the study effectively integrated to answer the research question? 5.3 Are the outputs of the integration of qualitative and quantitative results adequately addressed? 5.4 Are divergences and inconsistences between quantitative and qualitative results adequately addressed? 5.5 Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?
- Y = yes, the study meets the stated criterion
- N = no, the study does not meet the stated criterion
- NA = not applicable
- ? = can't tell if the study does or does not meet the stated criterion
- - = questions not used to screen

Appendix 5 Summary of included literature following full text screening

Reviewer 1: 92 items included following title/abstract screening: 62 included following full text screening; 14 excluded owing to NA; 1 excluded to NE

Reviewer 2: 93 items included following title/abstract screening: 48 included following full text screening; 9 excluded owing to NA; 1 excluded to NE

Total: 185 included papers following title/abstract screening; 110 papers following full text screening and initial data extraction

Reviewer 1:

Lead author (Surname) and Type of item	Date of publication and country of researchers/Research base	Full text screening code	How AI impacts radiology services' workload	Notes (disease and radiology professionals)
Abbas, Full conference proceeding – development and evaluation of AI	2020, Pakistan (50 X-rays)	3, 2	Transfer learning, faster R-CNN, for computer-aided diagnosis; automated fracture detection; X-rays	Lower limb fractures; Doctors/radiologists
Agrawal, Article – development and evaluation of AI: Efficient UNet	2022, India with data from US (138 CXRs; 108 948 frontal CXRs) and from China (public dataset 662 images (normal lungs and those with tuberculosis)	2, 2	Possibility of automated diagnosis – detection and definition; segmentation; CXRs	Lung disease; Radiologists
Aiello, Article – evaluation of AI	2022, Italy (validation dataset 73 CT images)	2, 2	Comparison of AI – segmentation tools; speed up diagnosis; CT images	COVID-19 (C-19) detection and monitoring; 'supporting diagnosis and quantification … lung lesions.' Radiologists
Alajmi, Article – development and evaluation of AI	2022, Saudi Arabia	3, 2	Machine learning with image analysis for automated C-19 detection; CXRs	C-19 detection; Radiologists
Alduraibi, Article – development and evaluation of AI	2022, Saudi Arabia (validation on 780 BU images – publicly available dataset)	2, 3	Convolutional neural networks and shallow classifiers; breast ultrasonography for diagnosis and differentiation; Enhance classification accuracy	Breast cancer (malignant vs. benign lesions); Radiologists/doctors

Ali, Full conference proceeding – development and evaluation of AI	2020, US (AI tested on 566 CXRs in publicly available dataset)	2, 3	Computer-aided diagnosis/detection (CAD); lung segmentation; second opinion in reading, increase objectivity; CXR	Lung disease (C-19, lung cancer, tuberculosis, pneumonia)
Allaouzi, Full conference proceeding – development and evaluation of AI	2021, Researchers in Morocco, international data sets (p. 60, example 5314 CXR images in one databased and dataset)	2, 2	Automated diagnosis; CXR	C-19 detection; Radiologists
Amara, Article – development and evaluation of AI	2022, Algeria (50 scans from MedMod data set – Italian)	3, 3	Novel neural network architecture for automated segmentation; virtual reality platform for reading and visualisation support for better interpretation; CT	C-19 detection; Radiologists
Antonios, Article – development and evaluation of AI	2013, Greece (BreDAn (clinical decision support system (CDSS)) clinical evaluated 534 MRI datasets; 3 case illustrations using BreDAn)	2, 3	Supplementation radiodiagnostic process, potential for automation with CDSS to CAD; captures exact pathological area through segmentation process; MRI	Breast pathology; Radiologists
Ardakani, Article – development and evaluation of AI	2020, Iran, Singapore, Malaysia, Taiwan (10 CNNs on 108 patients with C-19; 89 patients with other pneumonias)	3, 3	10 Convolutional neural networks (CNNs); RestNet-101 and Xception best performers as adjuvant tools detection C-19; CT	C-19 diagnosis; Radiologists
Benedikt, Article – evaluation of CAD on reading time	2018, Data from France and the US (525 cases)	3, 3	Computer-aided detection in digital breast tomosynthesis; CAD with DBT leads to 29.2% faster reading time	Breast screening; Radiologists
Calisto, Article – an exploration of how clinicians interact with AI	2021, Portugal (45 physicians across 9 clinical settings)	3, 3	Deep neural network (in human-centric AI) for automation and classification	Breast imaging; Radiologists

			for workflow efficiency and quality; 'high level of acceptance of AI .. reduction of cognitive workload … improvement in diagnosis'; Mammography	
Cao, Article – development and evaluation of weakly supervised learning	2022, China (1027 patients)	2, 3	Weakly supervised learning /Diffusion-weighted imaging (MR imaging); location of small stroke lesions; more sensitivity than human; reduce labelling workload	Acute ischaemic stroke and haemorrhagic infarction lesions; Radiologists
Chang, Article – development and evaluation of multi-objective deep learning model	2022, Taiwan (458 CT scans)	3, 3	Multi-objective deep learning; position, margin and texture lesions - quantitative lung diagnosis/report	Lung cancer; Radiologists
Chen, Article – AI development and evaluation (deep transfer learning)	2021, China (422 patients)	2, 3	Deep transfer learning; recognition and classification C-19; less time than radiologists, auxiliary diagnosis; CT images	C-19; Radiologists
Chen, Article – AI development	2021, China (3 data sets: ProMRI (gut MRI), ACDC (cardiology MRI) and REFUGE (retinal MRI) – international datasets)	3, 3	Weakly supervised segmentation; reduction in annotation costs; improved efficiency of delineation; MR images	Illustrative organ: prostate; Physicians
Clymer, Article – AI application	2020, US	2, 2	Convolutional neural networks and transfer learning (CNNs); enhanced prioritisation; reduction in arthrograms – un-necessary invasive intervention; 'second opinion' (p. 5); MR images	Glenoid labrum/shoulder labral tear; Physicians; Radiologists

Cunha, Article – AI development and evaluation	2020, US (484 patients)	3, 3	Segmentation and convolutional neural network (CNN); image quality evaluation and reduction in examination time – 48% examinations may have been reduced by applying CNN; MR images	Hepatocellular carcinoma screening/diagnosis; Radiologists
Dai, Article – development and evaluation of AI	2021, China (265 patients, 17050 CT images for training and validation of p-EffNet)	2, 3	Deep learning/supervised convolutional neural network; enhanced detection; CT images	Arterial stenosis in lower limbs; Radiologists
Dembrower, Article – evaluation of AI for triage (commercial product)	2020, Sweden (7364 women in study sample)	2, 2	AI cancer detector algorithm/deep neural network; AI as 'single reader … no radiologist involvement, and to select women for enhanced supplemental reading … by radiologist' (p. e472); Mammography	Breast cancer triage; Radiologists
Duron, Article – AI development and evaluation	2021, France (600 patients; 60 170 X-rays: 70% training, 10% validation, 20% internal testing)	3, 3	Deep convolutional neural network; Improved fracture detection, time efficiency in localisation of fractures; X-rays	Skeletal fractures; Emergency physicians and radiologists
Dyer, Article – AI (for triage) evaluation	2022, UK, US and India (390 CT head scans from UK and US for validation; 2059 CT scans for AI training)	3, 3	AI algorithm (EfficientNet neural network) with ground-truthing (to check the result of machine learning for accuracy); for AI to siphon abnormal scans to radiologist for expert reading, 'AI as a decision support system' (p. 740); CT scans	Intracranial haemorrhage, acute infarct; Ground-truth labelling by Consultant Radiologists (UK); AI for use in ED
Dyer, Article – evaluation of AI	2021, UK (UK data) (3887 CXRs from 3790 patients)	2, 3	Deep-learning/convolutional neural network; Automated	Diagnosis chest radiographs/CXRs; Radiologists

			detection of normal CXRs (High Confidence Normal) – potential to remove 15% examinations from radiology reporting workflow; 'DL … confidence scores and abnormal heatmaps (for non HCN)' (p. 473e.14)	
Feng, Full conference proceeding – AI development and evaluation	2021, China	3, 3	Computer-aided diagnosis (CAD) for 'diagnostic efficiency', 'for grading severity of knee OA' (p. 3796); X-rays	Knee osteoarthritis; Radiologists
Gaal, Full conference proceeding – AI development and evaluation	2020, Hungary (247 CXRs from Japanese Society of Radiological Technology; 138 CXRs from Montgomery; 662 CXRs from Shenzhen)	3, 3	Deep learning for organ segmentation; Fully convolutional networks; U-Net; CXRs	Chest X-rays in diagnostics for lung nodules, cardiothoracic ratio in cardiomegaly
Galvan-Tejada, Article – AI development and evaluation	2017, Mexico (publicly available: Breast Cancer Digital Repository BCDR-D01: 64 women and BCDR-D02: 164)	3, 3	Computer-assisted diagnosis for classification of benign and malignant lesions, 'detect abnormalities earlier' (p. 2), 'system .. potential … second opinion for … radiologist, or … practical use triaging mammograms' (p. 14); Mammography/X-ray	Breast cancer; Radiologists
Ghosal, Article – AI development and evaluation	2021, India (iSeg2017 dataset (US), 23 neonatal subjects and IBSR dataset (US), 18 MRIs from those 7 to 71 years)	2, 2	3D deep learning, Multi headed U-Net for tissue/organ segmentation; AI differentiate: gray matter, white matter, CSF; MR images	Brain MR images; Radiologists
Grauhan, Article – AI development and evaluation	2022, Germany (2700 shoulder radiographs for AI training)	2, 3	Convolutional neural network, ResNet-50; prioritisation of worklists; Radiographs/X-rays	Detect common causes of shoulder pain: fractures, joint dislocation, OA, periarticular

				calcifications, osteosynthesis and endoprosthesis; Physicians/clinicians
Hallinan, Article – AI development and evaluation	2021, Singapore (100 lumbar spine 'studies'/images)	3, 3	Deep learning, convolutional neural network, for classification tasks, 'semi-automated reporting under the supervision of a radiologist to provide more consistent and objective reporting' (p. 137); MR images	Detection/classification central canal, lateral recess and neural foraminal stenosis at lumbar spine MRI; Radiologists
Han, Article – AI development and evaluation	2022, China (public dataset: 1018 CT scans from 1010 patients	3, 3	Computer aided diagnosis (CAD) using 3D CNN; 'to help doctors pay more attention to those suspected early lung cancer nodules' (p. 11); CT scans	Pulmonary nodules detection; Doctors
Hidayah, Full conference proceeding – AI development and evaluation	2015, Indonesia (dataset from UCI Machine Learning Repository (US))	3, 3	Machine learning in clinical decision-tree (J48) with classification; No description of initial dataset AI based	Detection and classification of vertebral column pathologies; Radiologists
Hsieh, Article – AI development and evaluation	2021, China (37 427 sets of images of 19 041 patients at China Medical University Hospital)	2, 3	Deep learning, convolutional neural networks: ResNet and DenseNet; 'help physicians confidently and safely rule out bone metastases' (p. 11); whole-body bone scan	Bone metastases; Nuclear medicine physicians
Huang, Full conference proceeding – AI development and evaluation	2019, China (3111 brain images (T1-C images) from Shengjing Hospital)	2, 2	Gamma correction and deep learning, convolutional neural network to train classifier; Automation of brain tumour screening; 'radiologists … deal	Brain tumours; Radiologists

			with … "tumors"' (p. 52); MR images	
Hussain, Article – AI development and evaluation	2022, Malaysia (images/X-rays for model development from publicly available database)	3, 3	Convolutional neural network; Automated detection C-19 with second opinion for clinicians; CXRs	C-19 detection; Radiologists
Ismaeil, Full conference proceeding – AI development and evaluation	2020, Egypt (dataset from Lung Image Database Consortium dataset: 1018 thoracic CT scans with pulmonary nodules)	3, 3	Computer-aided detection, assistance in reading process; CT scans	Pulmonary nodules; Radiologists EXCLUDE? – limited focus on how AI impacts workflow; focus is on sliding windows in AI tool, detection of pulmonary nodules in 2D slices c.f. to usual 3D slices
Jacob, Full conference proceeding – AI development and evaluation	2021, India (888 CT scans from Lung Nodule Analysis challenge (US))	2, 2	Convolutional neural network, pre-trained ResNet-50; automated detection pulmonary nodules (malignancy)	Pulmonary nodules (less than 3cm compared to pulmonary mass more than 3cm); Radiologists
Jang, Article – AI evaluation for C-19 detection ('commercialized (deep learning) DL algorithm: Lunit INSIGHT for CR2' (p. 3))	2020, Korea (279 patients)	2, 3	Deep learning; 'facilitating rapid decisions … in-hospital isolation, treatment facilities, or self-quarantine orders in ED or screening clinics, particularly during pandemics ' (pp. 8-9); CXRs	C-19; Physicians
Jiao, Article – AI development and evaluation	2020, China (75 patients)	2, 3	Deep convolutional neural networks; Automation in breast segmentation and breast mass detection; '… potential value for early diagnosis and treatment	Breast cancer; Radiologists

			of breast cancer' (p. 10)'; MR images	
Jing, Article – AI development and evaluation	2022, The Netherlands (1447 breast MRI examinations of 809 patients)	2, 2	Deep learning (breast segmentation, maximum intensive projection generation and abnormality prediction); '… workload reduction of 30.6% at the breast level or 15.7% at the examination level' (p. n.p.)', '… 16.6% to 30.2% of scanner time could be saved over 178 examinations'; 'excluding normal scans and improving throughput by reducing scanning time … support radiologists' image interpretation'; MR images	Breast lesions; Radiologists
Johansson, Article – AI evaluation; Comparison of AI in radiology against detection by histopathology	2021, Sweden (120 patient examinations in evaluation)	3, 2	Computer-aided detection (CAD)/AI programme (Transpara), deep learning to detect malignant lesions; 'Transpara … to exclude low-risk cases … radiologists' workload (may be decreased) by 47% … (however) rate of missed cancer cases … 7%' (p. 5), best application of Transpara 'to preselect and exclude low-risk mammographs' (p. 5); Mammography	Malignant lesions in mammography screening' Radiologists
Joshi, Article – AI development and evaluation	2021, India, Czech Republic, Italy, Switzerland, Spain (dataset A (publicly available): 237 CXRs;	3, 3	Deep learning for automatic diagnosis; 'pre-screening', 'rapid disease detection in	C-19 detection; Radiologists

	dataset B (publicly available): 5848 CXRs; dataset C (Indian hospitals): 188 + 68 + 543 CXRs)		0.137 s per image … to generate probabilistic report in real-time'; CXRs	
Kakeda, Article – AI evaluation	2008, Japan (50 MR angiograms for observer performance study)	3, 3	Computer-aided diagnosis (CAD) to shorten reading time yet maintain MRA accuracy; 'mean reading time of less experienced radiologists with CAD was significantly shorter than that of neuroradiologists without CAD (39.8 vs 54.5 seconds …)' (p. 459); 'CAD did not improve the diagnostic accuracy of neuroradiologists …' (p. 464); MR angiography	Intracranial aneurysms; Radiologists/Neuroradiologists
Kasinathan, Article – AI development and evaluation	2022, India (94 individuals with PET/CT scans; training set: LIDC/IDRI 1024 cases)	3, 3	Cloud-based detector and classifier; deep learning; 'aid better decision-making'; PET/CT images	Classification of lung tumour; Radiologists
Keidar, Article – AI development and evaluation	2021, Switzerland and Israel (1384 CXRs of C-19+, 1024 CXRs of C-19-)	2, 3	Deep learning; automated diagnosis and monitoring, 'aid medical judgment …, improved turnaround times' (p. 9661); CXRs	C-19 detection; Radiologists
Khaled, Article – AI development and evaluation	2021, Spain (46 cases for evaluation from TCGA-BRCA collection (US))	3, 2	Deep learning, U-Net model, Automated segmentation – otherwise time-consuming manual activity; Dynamic Contrast Enhanced Magnetic Resonance Imaging (DCE-MRI)	Breast lesion segmentation; Radiologists
Kim, Article – AI development and evaluation/methodology	2018, UK (AI trained on 11112 images; tested on 100 wrist radiographs)	3, 3	Transfer learning from deep convolutional neural networks (CNNs); Automated fracture	Fracture detection; Radiologists

development (transfer learning)			detection, 'workflow prioritisation and minimisation of error' (p. 442); X-rays	
Lan, Full conference proceeding – AI development	2020, China (DDSM (US) database, publicly available, mammography samples: 2620)	3, 3	Deep convolutional neural network for computer aided diagnosis (CAD); Mammography	Breast cancer detection and classification; Radiologists
Lancaster, Article – AI evaluation (versus radiologist)	2022, The Netherlands and Russia (283 participants' ultra-LDCT scans used in evaluation)	2, 2	'… AI lung cancer screening prototype …' (p. 134); CAD; Workload reduction by up to 86.7%; 'AI as an impartial reader in ultra-low-dose CT lung cancer baseline screening ... outperforms all except one experienced radiologist … when looking specifically at negative misclassifications …' (p. 136), 'AI … as a first read filter …' (p. 138); CT scans	Lung nodule detection; Radiologists
Lauritzen, Article – AI evaluation	2022, Denmark (114 421 screenings for breast cancer in 114 421 women)	2, 2	AI = Transpara (p. 43); CAD; Radiologist workload reduction by 62.6%, and 25.1% of false-positive screenings; Mammography	National (Denmark) biennial breast cancer screening; Radiologists
Li, Full conference proceeding – AI development and evaluation	2020, China (68 low-dose 3D CT images from pre-op. patient with TAPVC)	2, 2	Deep learning for automated segmentation; '… improve the efficiency and reduce the workloads of radiologists (400 milliseconds vs. 2-3 hours per-case)'; CT images	Segmentation for total anomalous pulmonary venous connection (TAPVC); Radiologists
Li, Article – AI evaluation	2021, China and US (498 3D images across 2 body regions (head and neck and thorax) IRB from US))	2, 2	SparseGT (AI); automated segmentation; 'over 90% workload reduction is workload	Automate segmentation with AI; Radiologists

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			feasible'; CT scans of head and neck and thorax	
Lin, Article – AI development and evaluation	2022, China (VinDR-CXR – large publicly available dataset)	3, 3	Computer-aided diagnosis; Automated detection; CXRs	Multiple lung lesion detection and classification
Liu, Article – AI evaluation	2020, China (590 patients underwent CTPA – training set; 288 patients in validation set)	2, 3	Fully deep learning convolutional neural network – U-Net; CTPA (CT pulmonary angiography)	Acute pulmonary embolism detection and quantification of clot burden; Radiologists
Liu, Article – AI evaluation	2021, China (800 ALN lesion samples)	3, 3	Traditional machine learning and deep learning to predict ALN metastasis … CECT images … with segmentation; 'to assist … in determining ALN metastasis …'; CT images	Axiliary lymph node metastasis prediction; Doctors
Loizidou, Full conference proceeding – AI development and evaluation	2021, Cyprus (160 images)	3, 3	Temporal subtraction of sequential mammograms, image registration and machine learning; CAD system to 'assist' radiologists; Mammography	Automated detection and classification of breast masses; Radiologists
Luo, Article – AI development and evaluation	2022, China (71 patients)	3, 3	Convolutional neural network; Automatic detection and segmentation of the thyroid gland; Ultrasonography	Automated detection and segmentation of thyroid gland
Ma, Article – AI development and evaluation	2022, China ('… millions of natural images' (p. 366)	3, 3	Densely connected convolutional network (SDenseNet and Mul-DenseNet); '… reduce heavy workload … avoid misdiagnosis'; Ultrasound	Automatic joint segmentation of thyroid and breast lesions; Physicians
Ma, Article – AI development and evaluation	2017, China (1004 CT cases)	3, 3	Radiomics; automatic detection, reduction of error; CT scans	Lung nodules; Radiologists

Mahmood, Full conference proceeding – AI development an evaluation	2021, Australia (60 CT scans for training, testing and validation)	3, 3	Deep learning – U-net; Automated segmentation; CT scans	Automatic segmentation of thoracic organs; Radiologists
McKinney, Article – AI evaluation	2020, UK and US (25 856 women)	3, 3	Deep learning; AI provided non-inferior performance, Workload reduction of second reader by 88%; Mammography	Automation of stages of national breast screening in UK and application in US; Radiologists
Meng, Article – AI development and evaluation	2019, US (480 radiology reports)	3, 3	Machine learning; AI – online decision support system …. identify radiological cases for prompt communication to referring physician	Reporting efficiency; Radiologists
Monkam, Article – AI evaluation	2018, China (publicly accessible database: LIDC/IDRI – 1018 CT scans from 1010 patients)	3, 3	CNN models; Reduction false positives; CT images	Lung nodules; Radiologists

Reviewer 2:

Lead author (Surname) and Type of item	**Date of publication and Country of Research**	**Full text screening code**	**How AI impact radiology services' workload**	**Notes (Disease and radiology professionals)**
Noshad, Article – AI development and evaluation	2021, Iran (219 C-19, 1341 normal images, 1345 viral pneumonia from Qatar University, University of Dhaka, collaborators from Pakistan and Malaysia)	3, 3	Deep residual neural network; Assist in initial screening, 'second opinion … decreased workload … more accurate diagnoses'; CXRs	C-19 detection; Radiologists
Pan, Article – AI development and evaluation	2021, China (3555 MR images)	3, 2	Deep convolutional neural networks; Automated diagnosis disc bulge and herniation; 'improve diagnostic efficiency'; MR images	Lumbar disc bulge, disc herniation; Radiologists

Parascandolo, Article - AI development and evaluation	2015, Italy (57 patients)	3, 3	RheumaSCORE: A CAD (via semi-automated segmentation) for rheumatoid arthritis diagnosis; MRI	Rheumatoid arthritis; Radiologists
Pedrosa, Article – AI development and evaluation	2022, Portugal (3 public datasets, 1 private dataset – international)	3, 3	Deep learning; Second opinion to support triage of C-19; Assess clinical applicability of deep learning for C-19 screening; CXRs	C-19; Technicians and radiologists
Polat, Article – AI development and evaluation	2021, Turkey (102 CT images for evaluation from 2 publicly available datasets)	3, 3	Deep convolutional neural networks; 'COVID-19 pneumonia … localized automatically … lesion densities can be … evaluated quantitatively'; CT images	C-19 pneumonia; Radiologists
Pongsakonpruttikul, Article – AI development and evaluation	2022, Thailand (1650 knee radiographs – publicly available)	3, 3	Deep learning; 'diagnostic aids', 'interpretation and classification of knee OA …'; X-rays	Knee osteoarthritis; Physicians (including radiologists)
Postalcioglu, Article – AI development and evaluation	2022, Turkey (dataset from Kaggle: 2400 CXRs? for training and 600 for testing)	2, 2	Boosting techniques/gradient boosting machine learning; Automated diagnosis, 'pneumonia diagnosis … quickly and accurately by anyone using X-ray' (p. 14); CXRs	Pneumonia (C-19); Doctors/radiologists
Prasad, Full conference proceeding – AI development and evaluation	2022, India (C-19 dataset collection from Kaggle, CXRs	3, 3	CNN, deep learning; 'diagnostic decision support device'; CXRs	C-19 detection; Radiologist
Purkayastha, Article – AI development and evaluation	2020, US (>100 000 CXRs from publicly available dataset - CheXNet)	3, 3	Neural network algorithm; 'turnaround time of under 30 s'; 'feasibility of a web service for machine learning based diagnosis of 14 lung	Thoracic diseases; Radiologists

			pathologies' (p. 1), Aim for implementation in areas of few radiologists; CXRs	
Qi, Article – AI development and evaluation	2021, China (130 NPC patients – CT; 149 NPC patients – MR images)	3, 3	Computer-aided diagnosis and regional segmentation for treatment; Automation of diagnosis and treatment planning; CT and MR images	Nasopharyngeal carcinoma; Radiologists
Qiu, Full conference proceeding – AI development and evaluation	2018, China (312 patients)	3, 3	Texture analysis method/radiomics; '… reference for diagnosis … reference value for the quantitative data research … pancreatic lesions …' (p. 12); CT images	Pancreatic cancer; Radiologists
Ragab, Article – AI development and evaluation	2020, Egypt (SARS-CoV-2 CT-scan dataset from Brazil: 1252 CT images/60 patients and 1230 CT images/60 patients)	3, 2	FUSI-CAD, convolutional neural networks; 'proposed system …. simple to set up, low cost, and automated CAD … accurate, effective, and fast diagnostic tool … early diagnosis' (p. 20); CT images	C-19 diagnosis; Radiologists
Rajaraman, Article – AI development and evaluation	2021, US (Multiple international datasets see pp. 5-7)	3, 3	U-Net models for semantic segmentation; 'TB classification and segmentation' (p. 27), 'advanced assistance in radiologist interpretive workflows: … triage … classification … improving productivity …' (p. 28); CXRs	Tuberculosis; Radiologists
Rao, Article – AI application and evaluation	2021, US (6565 non-contrast brain CT scans)	2, 3	AI 'adjunct to current peer review tools as a second reader …' (p. 92); CT images	Intracranial haemorrhage; Radiologists

Raya-Povedano, Article – AI development and evaluation	2021, Spain (15 987 digital mammography and digital breast tomosynthesis examinations)	2, 2	AI/Transpara with DBT would result in 72.5% less workload and AI with DM would result in 29.7%; '… screening workload could be safely reduced up to 70% for both digital mammography (DM) – and digital breast tomosynthesis (DBT) …' (p. 64); DM and DBT images	National breast screening programme; Radiologists
Rodriguez-Ruiz, Article – AI application and evaluation	2019, The Netherlands, Switzerland, Italy, Austria, Spain, Germany and Sweden (2652/2654? DM examinations)	2, 2	AI/CAD for triage; AI mid-point score … halving workload …; Mammography	Breast screening programme
Saba, Article – AI development and evaluation	2022, Saudi Arabia (780 images)	2, 3	CAD, convolutional neural networks; 'CAD … help … identify malignant cases with minimal time and effort …' (p. 7); Breast ultrasound images	Breast ultrasound; Radiologists
Salem Salamh, Article – AI development and evaluation	2021, Turkey (800 images in development)	2, 3	Convolutional neural network, VGG/GK-Tool; 'good recognition rates in the diagnosis … could reduce the radiologist's workload' (p. 1); CT images	C-19 detection and classification; Radiologists
Seidel, Full conference proceeding – AI development and evaluation	2015, US (NCI Lung Image Database Consortium (LIDC) dataset)	2, 2	CAD; '… metric-based case partitioning can be used to better select … radiologists assigned to each case … further assist with diagnosis … to shed 25% of radiologist annotations	Diagnostic consensus in image interpretation; Radiologists

			without any loss of predictive accuracy' (p. 771); CT	
Sheela, Article – AI development and evaluation	2022, India (200 training cases/MR images)	2, 2	AI algorithm; '…classify the presence of pneumonia which will in turn save around 50% of the time frame for physicians …' (p. 2049); MR images	C-19 detection, early stage
Shibata, Article – AI development and evaluation	2021, Japan (3845 subjects non-contrast head CTs)	2, 2	Semi-supervised flow-based generative models for 'versatile anomaly detection method' (p. 1), 'reduce the workload for labeling' (p. 5); CXRs and brain CTs (BCTs)	Lesion detection and qualification; Radiologists
Shimada, Article – AI development and evaluation	2020, Japan (1623 subjects, 5 subjects with missed aneurysms initially)	3, 3	CAD using convolutional neural network; 'CAD … might pave the way to substitute the workload of diagnostic radiologists and reduce the cost of human labor' (p. 4); MR images	Cerebral aneurysms; Radiologists
Shoshan, Article – AI development and evaluation	2022, US (13 306 DBT examinations/9919 women; model tested on 4310 screened women)	2, 2	'… use of AI to automatically filter out cases would result in 39.6% less workload … 25% lower recall rate'; digital breast tomosynthesis (DBT)	Breast screening; Radiologists
Sichtermann, Article – AI development and evaluation	2019, Germany (85 examinations)	3, 2	Deep learning convolutional neural network; Automated detection (CAD) of intracranial aneurysm (IA), 'potential for reliable detection of (IA) from 3D TOF-MRA' (p. 30), '(CAD) …	Intracranial aneurysms; Radiologists

			preventing diagnostics errors … physician's fatigue' (p. 30)	
Siddiqui, Article – AI development and evaluation	2020, Pakistan (527 images)	3, 3	Deep learning, convolutional neural network; CT scans and X-rays	C-19 detection; Radiologists and medical practitioners
Su, Article – AI development and evaluation	2021, China (1018 patients)	2, 2	Convolutional neural network; Automated lung nodule detection; 'reduces … rate of misdiagnosis and missed diagnosis'; CT images	Lung nodule detection; Radiologists
Tandungan, Full conference proceeding - AI development and evaluation	2019, Indonesia (use of LIDC-IDRI dataset)	3, 3	CAD/Extreme Learning Machine for automated diagnosis, 'help radiologists in analyzing lung cancer nodules …' (p. 1); CT scans	Lung cancer classification
Tsai, Full conference proceeding – AI development and evaluation	2012, Taiwan (4 datasets – no additional information)	2, 3	CAD/Multiple Active Contour Models and Gabor Neural Network; Diagnostic accuracy; CT	Pulmonary embolism; No clinician group identified
Tsai, Article – AI development and evaluation	2022, Taiwan (5733 mammograms/1490 patients)	2, 3	Deep neural network; Mammographic interpretation; Mammograms	Breast screening; Radiologists
Van den Oever, Article – AI development and evaluation	2020, The Netherlands (60 scans)	3, 2	Deep learning; Automated detection/exclusion or segmentation on cardiac CT of coronary artery calcium; cardiac CT images	Coronary artery calcium (CAC) detection; Radiologist
Verburg, Article – AI development and evaluation	2022, The Netherlands (4581 breast examinations)	3, 2	Deep learning; Automated triaging to differentiate breasts with lesions and those without … to dismiss from radiologic review; MRI examinations	Breast screening; Radiologists

Vilares, Full conference proceeding – AI development and evaluation	2021, Portugal (259 mammograms with lesions, 255 normal)	3, 2	Deep learning; Triage complex from normal to enable radiologists to focus on complex; Mammograms	Breast screening; Radiologists
Wang, Article – AI development and evaluation	2018, China (2480 images from public datasets)	3, 3	Deep learning; '… provide physicians and radiologists with valuable information to significantly decrease time-to-diagnosis' (p. 16); CXRs	Lung lesions; Radiologists
Wang, Article – AI development and evaluation	2021, China (25000 scans to develop model; validation 75 and 491 scans)	3, 3	Deep learning, 2D CNN model; Automated detection and classification of AIH; 'prompt and better decision-making' (p. 1), 'second-read or triage tool' (p. 1); CT scans	Acute intracranial haemorrhage; Radiologists
Wong, Full conference presentation – AI development and evaluation	2019, US (>100 000 images from 30 000 patients from NIH Clinical Center)	2, 2	'Deep learning framework (CNN model) for normal/abnormal classification (of chest X-rays)' (p. 6); 'average recall of 50% … cut in half the number of disease-free CXRs examined by radiologists' (p. 1); CXRs	Disease-free CXRs; Radiologists
Wu, Article – AI development and evaluation	2020, China (495 patients from 3 hospitals)	3, 3	Deep learning; 'improve the efficacy of diagnosis' (p. 1); CT images	C-19 screening; Radiologists
Yala, Article – AI development and evaluation	2019, US (223 109 screening mammograms of 66 661 women 2009 – 2016)	2, 2	Deep learning to triage/pre-selecting mammograms; 'cancer free' not reviewed by radiologist; 'workload reduction of 19.3%' (p. 43)	Screening mammograms; Radiologist

Yan, Article – AI development and evaluation	2020, China (206 C-19 patients with 416 CT scans and 412 CP patients with 412 CT scans)	2, 2	Deep learning; multi-scale convolutional neural network (MSCNN); 'rapid diagnosis'; CT scans	C-19 distinction from common pneumonia; Radiologists and physicians EXCLUDE? – minimal detail re: impact on radiologist/physician workload beyond 'quick diagnosis'
Yang, Article – AI development and evaluation	2020, China (295 patients)	2, 3	Deep learning; DenseNet; Improved diagnostic efficiency; CT scan	C-19 detection; Radiologists
Yang, Article – AI development and evaluation	2021, China (2749 cases)	3, 3	AI-powered mammographic breast lesion diagnostic system; Accelerate diagnostic process; Mammography	Mammography screening; Radiologists
Yao, Article – AI development and evaluation	2021, China (1707 patients)	3, 3	Deep learning; 'superior recall and similar diagnostic precision to (experienced) radiologists' (p. 8); CT scans	Rib fracture detection; Radiologists
Yates, Article – AI development and evaluation	2018, UK (ChestX-ray14 from NIH: 112 120 images from 30 000 patients and 7470 from Indiana University hospital network chest radiograph database)	3, 3	Open-source, cloud, deep convolutional neural networks; 'classify chest radiographs as normal or abnormal'; CXRs	Chest radiograph classification; Radiologists
Zamacona, Article – AI development and evaluation	2015, US (LIDC dataset)	2, 3	CAD; Categorising diagnostic complexity, 'determine the easy from hard …'; '… best allocate additional radiologists to interpret a case based on its diagnostic category'; CT scans	Lung nodule image dataset used for AI development; Radiologists

Zapaishchykova, Article – AI development and evaluation	2021, US (373 admission CT scans from 2 level 1 trauma centres)	2, 3	Faster-RCNN; automation; 'prioritize the reading queue of the attending trauma radiologist'; 'extract pelvic-fracture-related risk scores' (p. 425); CT scans	Pelvic trauma severity scoring; Radiologists
Zhang, Article – AI development and evaluation	2019, China (18 cases, 8 with lung ca. and 10 without)	2, 3	Computer-aided diagnosis, Multiscale Mask R-CNN; 'effectiveness of method in detecting lung tumors along with the capability of identifying a healthy chest pattern and reducing incorrect identification of tumors …'(p. 1); PET imaging	Lung tumour detection
Zhang, Article - AI development and evaluation	2021, China (416 C-19 CT scans from 216 patients, 412 CP CT scans from 412 patients)	2, 2	U-Net and ResNet-18; Segmentation and classification; 'assisting physicians and radiologists in rapid COVID-19 detection'; CT images	C-19 detection
Zhao, Full conference proceeding – AI development and evaluation	2022, China (400 patient with confirmed glioma)	3, 3	CAD, Radiomics; 'reduce time of manual segmentation'; MR images	Glioma grading; Radiologists
Zhou, Article – AI development and evaluation	2020, China (1079 patients)	2, 3	Faster R-CNN; Automatic detection and classification; CT scans	Rib fractures on thoracic CT scans; Radiologists

<u>Notes</u>

Full text screening codes:

- '2's about volume of images
- '3's about efficiency

Exclusions:

- NA – full paper/article not available: 23
- NE – not in English: 2
- Review - 3: Ahmad (2021); Sechopoulos and Mann (2020); Shi et al. (2020)
- Conference abstract only – 6: Hernandez et al. (2021); Raghav et al. (2020); Tan and Parizel (2021); Tomori et al. (2018); Vonder et al. (2021); Yuan et al. (2018)
- AI for other staff groups beyond clinical radiology services with diagnostic remit – 5: for example, radiologists and dentists (Chen et al. 2020); physician workload (Clymer et al. 2020); orthopaedic surgeons (Li et al. 2019); obstetricians (Liu et al. 20220); radiologists and neurosurgeons (Shi et al. 2020)
- Radiotherapy - 3: Choi et al. (2020); Huang et al. (2021); Olsen et al. (2012)
- AI for treatment follow-up – 4: El Adoui et al. (2019); Sullivan et al. (2020); Zhao et al. (2020); Zhao et al. (2022)
- AI during surgery – 2: surgery navigation (Hu et al. 2022); surgical planning (Li et al. 2021)
- AI development – 10: Park et al. (2021); Peng et al. (2021); Petrov et al. (2017); Shu et al. (2020); Sotoudeh-Paima et al. (2022); Sun et al. (20221)/Peng et al. (2021); Tamer et al. (2022); Yeh et al. (2018); Yu et al. (2020); Yu et al. (2021)
- AI for communication/reporting – 3: Spandorfer et al. (2019); Yuan et al. (2019); Zhang et al. (2020)
- Evaluation of AI with limited explanation of impact on radiology workload – 5: Lin et al. (2021); Taylor et al. (2008); Vorontsov et al. (2019); Yang et al. (2021) – 'Integrate domain knowledge …'; Zeng et al. (2021)
- Other technology – 7: Miles et al. (2018); Mizan et al. (2021); Mohsen et al. (2014); Patil et al. (2016); Ritchie et al. (2016); Taylor (2015); Vasilakakis et al. (2019)
- Other – 2: Van den Biggelaar et al. (2009) – use of breast technologists in pre-reading mammograms; Yamaguchi et al. (2020) – study protocol

Simple flowchart to show numbers of excluded articles as each stage of the paper/article selection process: