An exploration of Education, Experience and Social Factors on CT Dose Optimisation

by

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Abstract

Background: The number of Computed Tomography (CT) scans in England is likely to increase by 100% in next five years. In a medical emergency or in the presence of complicated pathology such as oncology indications, CT scanning is essential, and the benefit outweighs the risk. In CT scanning, patients should receive the optimal level of radiation to achieve a clinically diagnostic image. Vulnerable groups are particularly sensitive to the ionising radiation dose from CT scanning, which could cause cancers in the future. The amount of radiation from a CT scan is disproportionately high when compared to projectional X-ray imaging technology. Radiographers are required to adjust exposure parameters and scanning technique to achieve a clinically diagnostic image with the optimal level of radiation. Collaborative working with radiographers, radiologists, clinical scientists, and application specialists is required to effectively optimise CT parameters giving maximum image quality for minimum radiation exposure. There is a national and world-wide shortage of radiographers, radiologists, clinical scientists.

Emotional Intelligence (EI) has a part to play in learning in the clinical environment, since it is important that radiographers are aware of theirs and others' emotions, including patients and supervisors, this is believed to increase after qualification.

In a study of European Union (EU) CT radiographers it was found that there was a need for ongoing education to ensure that CT exposure parameters are adapted to optimise patient dose and that the effect of changing some of the parameters was not well understood. This study set out to explore if this held true in United Kingdom (UK) CT radiographers and explore social factors' influence in the clinical environment.

Aim: The Aim is to identify training requirements for UK CT radiographers regarding specifically social and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation.

Research question: Through evaluation of radiographers' views, experiences and perspectives using mixed methodology, what are the factors that will contribute to holistic dose optimisation within the clinical environment?

Methods: This Mixed Method study consisted of three linked convergent parallel methods, integrating, and connecting quantitative and qualitative data proceeded by three linked literature reviews. Cross-sectional, longitudinal, qualitative, and systematic review methodology was used.

Results and findings: Only 9% of radiographers in the cross-sectional study reported that multidisciplinary team working was occurring in their department. Over a third (36%) of radiographers in the cross-sectional study were concerned about the CT doses in their departments. Most UK radiographers (98%) felt that they required further training in optimisation of CT parameters.

Ongoing education is a key requirement. Knowledge of exposure parameters significantly increased (p=0.0085) from pre- to post-registration radiographers. Wellbeing and emotionality increased significantly (p=0.039 and 0.047 respectively) from pre- to post-registration radiographers, although their global emotional

intelligence score was not significantly different. Pre-and post-registration radiographers appreciated the need to adjust exposures for children although they may not have seen the adjustments in practice at this stage of their careers.

The longitudinal study qualitative data identified three themes which were: Education, Culture, and Dose optimisation. The longitudinal study showed that post-registration radiographers had expanded their knowledge about the use of automatic tube current modulation (ATCM) when a patient had a metallic implant.

The experienced radiographers felt that most CT education was delivered in-house, which was the preferred method in the longitudinal study. In the UK cross-sectional study radiographers had reservations about in-house CT education since they felt that radiographers who did not have complete knowledge of CT were educating other radiographers.

Radiographers' training is unable to keep up with the rapidly advancing technology of modern CT scans. Current knowledge of dose optimisation techniques are essential knowledge for radiographers. Radiographers taught their CT skills at undergraduate level can only keep up-to-date by participating in regular CT professional education, requiring a multi-disciplinary team approach.

Advanced CT radiographers still feel that they require more knowledge and applications training before they can manipulate exposure parameters, this feeling being cascaded through the workforce to pre-registration radiographers. Compounded by ever increasing scan numbers and lack of staff, radiographers feel that they needed to protect their 'free time' for relaxing and leaving less time for education outside their 'work time'.

Some pre-registration and newly qualified radiographers felt poorly supported because trained professionals were too busy to pass on knowledge. Where knowledge was being actively taught, the experts in their field were unlikely to have formal clinical supervision or education training and the training would occur on an ad hoc basis. Currently most CT skills are being taught in the clinical environment, but this training is not producing newly qualified radiographers who are competent in cross-sectional imaging. There seems to be a lack of clinical reasoning and critical thinking regarding CT dose optimisation.

Radiographers must be empowered to operate the technically complex equipment whilst undergoing the challenge of the balance between emotions of self, patients, and teacher/learner with all their complications. The COVID-19 pandemic has added another layer of barriers to learning, along with influencing the emotions of staff and patients.

Conclusion : This study has shown that learning in the clinical environment is complex and there is an urgent requirement for professional education to keep pace with technological advances in CT scanning. There should be an acknowledgment that good teaching and training in the clinical environment is an essential investment in the future workforce. Advanced radiographers should be offered continuous bespoke CT training, with a multi-disciplinary team approach, to keep abreast of current advancements. These radiographers should be given the time and expertise in clinical supervision and education to set out effective training programmes for pre- and post-registration radiographers in the clinical environment.

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Glossary

ALARA - As Low As Reasonably Achievable

ALARP - As Low As Reasonably Practicable - the same as ALARA but used in UK law.

ATCM - Automatic tube current modulation - adjusts tube current to accommodate high to low attenuation

CBS - Computer-based simulated

CLE - Clinical Learning Environment

CNR - contrast-to-noise ratio

COMARE- The Committee on Medical Aspects of Radiation in the Environment

CPD - Continuous Professional Development

CT - Computed Tomography

CTDI vol - Computed tomography dose index -dose output from the scanner from a single rotation.

CT Sim - educational software allowing users to set CT parameters and observe the effects of the changes

CQC - Care Quality Commission.

Caudally cranially - orientation of the movement of the CT scanner, scan from feet to head

Cross-sectional imaging - Diagnostic imaging techniques that view the body in cross-section (axial) slices, such as CT and MRI scanning.

Deterministic effect - related directly to the absorbed radiation dose and the severity of the effect increases as the dose increases.

DLP-Dose-length-product -the radiation dose over the whole scan-CTDI x length of coverage.

DRL- diagnostic reference levels - dose levels in medical imaging for typical examinations.

EI - Emotional intelligence

FOV - Feld of View- The anatomical area selected to be scanned.

Hybrid imaging - The fusion of one (or more) imaging modalities e.g., PET-CT. Can shows anatomical and physiological imaging fused on one image.

IAEA - International Atomic Energy Agency

IR(ME)R - Ionising Radiation (Medical Exposure) Regulations - UK Radiation law concerned with radiation exposures to patients, individuals in health screening programmes, asymptomatic individuals, research, carers and comforters and people participating in research studies involving ionising radiation.

Isocentre - The interaction of the central scan plane with the axis of rotation of the X-ray tube and detector around the patient.

Justification - Consideration that the medical exposure shall show a sufficient net benefit taking into account benefits, risks and alternative imaging.

kVp - kilovoltage peak. The highest voltage that will be produced by the X-ray tube during an exposure.

LAR - Lifetime attributable risk

mA - The tube current

mAs- mA combined with the X-ray tube rotation time, milliampere-second

MEG- Medical Exposures Group

Modality - Diagnostic modality is the way in which a disease or illness is diagnosed by a doctor. Modality is used in imaging departments to describe each type of specialised scanning such as CT, MRI or US.

MPE - Medical Physics Expert

MRI- Magnetic Resonance Imaging

NICE - National Institute for Health and Care Excellence (NICE) PET - Positron Emission Tomography

OBTCM - Organ-Based Tube Current Modulation - aims to reduce dose to radiosensitive organs

OECD - Organisation for Economic Co-operation and Development (OECD) is an international organisation where governments work together to find solutions to common challenges.

RCR- Royal College of Radiologists

SoR- Society of Radiographers

Stochastic effect - a random probability effect

Topogram or scout phase- This is a low dose pre-scan phase, where the desired FOV is scanned so the tube current variations can be calculated by the scanner.

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Chapter 1- Introduction

1.1 Background

This study sets out to explore the links between the complex interconnections that contribute to computed tomography (CT) dose optimisation. There are concerns surrounding the use of CT scanning due to its high radiation dose when compared to projectional radiography such as chest X-rays, with a routine thorax CT scan delivering a radiation dose 50 times higher than a conventional chest X-ray (Joyce et al., 2020). The number of CT scans being performed is increasing year on year in most countries including the United Kingdom (UK) (Tsapaki, 2020; Dixon, 2020; NHS England 2020).

Current knowledge of dose optimisation techniques is essential for radiographers, allowing them to scan in an effective way producing diagnostic images with minimum radiation dose to the patient (Foley et al., 2013). Ongoing education is a key requirement for radiographers, empowering them to remain competent using a rapidly advancing technology and to teach the future workforce in the clinical environment (Sloane and Miller, 2017). The modality of CT scanning is highly pressured and demanding, relying on positive social interactions to cope with the intense pressure as a team (Nightingale et al., 2021). Radiographers do not work alone, CT protocols, sequences and optimum exposure parameters need to be set by a collaborative team in the clinical environment and this is particularly important for vulnerable groups such as children (Elliott, 2014).

Educational, psychosocial, and clinical factors all contribute to effective dose optimisation, Figure 1.1 shows a schematic representation of their relationship.

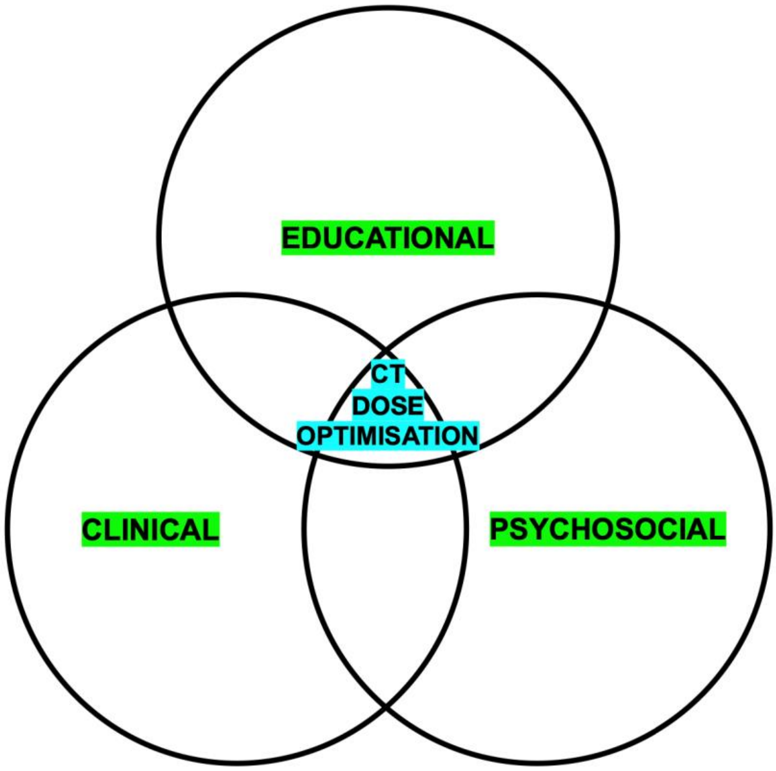

Figure 1.1 - *Venn diagram of factors contributing to CT dose optimisation*

CT scanning has a disproportionate contribution to radiation exposure of patients compared to other ionising radiation-based imaging modalities (Elliott, 2014). Smith-Bindman (2019) concluded that a variation in CT doses across countries is primarily attributable to local choices regarding technical parameters and there is a steady rise in the proportion of radiology notifications of errors involving CT scans (Care Quality Commission, 2017). CT scanning is a technically complex modality and with increased throughput, radiographers are under increased pressure, compounded by chronic staff shortages (Seeram, 2018; NHS England, 2020).

The Committee on Medical Aspects of Radiation in the Environment (COMARE), 16th Report, reported on patient radiation dose issues resulting from the use of CT in the UK and the chairman of the report took the unusual step of publicising the findings to the national newspapers (Elliott, 2014). The Guardian newspaper headlined with 'Cancer fears prompt call to cut hospitals' CT scan radiation levels. The article included the facts that the risk is low but one in 2000 will develop cancer from an abdominal CT scan, and that hospitals must ensure their staff are trained to precisely adjust the CT settings, ensuring the optimal level of radiation is delivered to each patient (Boseley, 2014; Elliott, 2014). Foley et al., (2013) concurred with The COMARE report findings, concluding that there was a need for ongoing education to ensure that CT exposure parameters are adapted to optimise patient dose and that the effect of changing some of the parameters was not well understood. Collaborative working between radiologists, radiographers, medical physicists, and manufacturers is required to optimise the CT exposure parameters (Foley et al.,2013; Elliott, 2014; Chell, 2016).

CT scanning is complex, and many factors contribute to dose optimisation and producing a final diagnostic image. This background section is a review of the intricate aspects contributing to these factors.

1.1.1 Increasing number of scans

Six million CT scans were undertaken in England 2019-2020 representing a 5.2% increase on the 2018-2019 data (Dixon, 2020). Along with the increase in CT scans, CT scans as part of hybrid imaging increased by 12.5% (Dixon, 2020). Hybrid imaging is where CT is added to another type of imaging such as positron emission tomography (PET) scanning, which creates a functional image and the CT component creates an anatomical image (Vosper et al., 2021). Although there was a slight reduction in CT scans in the 2020-2021 data, due to COVID-19 pandemic, demand is likely to increase 100% in the next five years (Dixon, 2021; NHS England, 2020).

Although the numbers of scans in the UK is increasing, the UK has nine CT scanners per million inhabitants, compared with 42 and 47 for USA and Iceland respectively (OECDa, 2022). From the 2017-2020 data, the UK undertook 103 CT examinations per 1000 inhabitants compared to USA and Iceland with 220 and 217 scans respectively (OECDb, 2022). From the data it can be seen that the UK is scanning approximately half the number of patients per head of population with a fifth of the scanners leading to CT departments working to maximum capacity.

There is an over reliance on CT scans particularly in young patients which contributes to the rising number of scans performed. Shobeirian et al. (2021) found a 15% overuse of CT head scans in young people, which was defined as under 75 years old in this study, with over a third of them being referred after falling, the mean age was almost forty but had a confidence interval (CI) of 20 years. Cellina et al. (2018) reinforced the overuse of CT scanning in minor head injuries, in their study of patients under 45 years old only 2% of the 493 patients had a positive scan. The low positive scan rate could be due to poor clinical examination of the patient and rapid access to CT facilities (Cellina et al., 2018). Unnecessary CT scans not only contribute to the numbers of scans but the patient's cumulative radiation exposure which is particularly important in patients under thirty years of age who are referred for repeated CT scans (Kritsaneepaiboon et al., 2018).

CT scanning should be used where it is appropriate. In major trauma CT scanning is vital, with an increase from half to three quarters of major trauma patients having a CT scan in the nine years after the redesign of Major Trauma Units in the England contributing to the improved care and outcomes of patients (Moran et al., 2018).

1.1.2 Dose optimisation

The increasing number of CT examinations performed means that dose optimisation is of paramount importance because the risks from CT radiation dose are real, leading to stochastic (chance) effects (Brenner and Hall, 2012; Elliott, 2014). The radiation dose risks from CT scans depend on the age of patient, area of the body scanned, the sex of the patient, and the type of scan performed (Elliott et al., 2024). Wall et al. (2011) estimated the typical effective radiation dose for a CT chest, abdomen and pelvis to be 10 mSv, which would give a lifetime cancer risk of 520 and 740 per million for 30–39-year-old male and females respectively, reducing to 2.1 per million for a 90-year-old and increasing to 1500 for a 0–9-year-old female. It has been discovered that patients exposed to a radiation dose of more than 7.5 mSv during their cardiac CT scan have evidence of DNA damage (Nguyen et al., 2015). Reducing the typical effective radiation dose can reduce the lifetime risk of cancer since the probability of radiation induced cancers decreases as the radiation dose reduces (Joyce et al., 2020). There is no safe level of ionising radiation, and hence there will always be a dose-benefit trade-off which has to be optimised (Peck and Samei, 2017).

The fundamental principles of radiation protection are justification, optimisation, and limitation (International Commission on Radiation Protection (ICRP), 2007). During the process of justification, the potential benefits and detriments to the patient must be considered. If non-ionising radiation imaging techniques, such as Magnetic Resonance Imaging (MRI), are more appropriate then the optimal method of reducing radiation dose is to avoid unnecessary CT scans (IR(ME)R, 2017 (SI 2017/1322), Joyce et al., 2020). Justification is particularly important because the referrer may not be aware of the typical effective radiation dose to the patient from a CT; studies suggest that between three fifths and three quarters of referrers underestimate the dose from a CT scan (Lee et al., 2012; Singh et al., 2015).

There is an overuse of CT scans, with Cellina et al. (2018) discovering that 70% of patients scanned for minor head injuries did not meet the National Institute for Health and Care Excellence (NICE) guidelines. Robust justification needs to occur to protect patients from having unnecessary CT scans. Hall et al. (2021) are so concerned about the overuse of imaging, including CT scanning, in lower back pain that they have issued a ‘practice change’ educational article to stop UK clinicians referring patients for CT scans in their Ionising Radiation (Medical Exposure) Regulations 2017(IR(ME)R) role as referrer. Referrers’ have a legal requirement in regulation 6(2) to comply with written procedures (IR(ME)R, 2017 (SI 2017/1322).

Best practice in radiation protection denotes that the radiation dose from CT scans should be As Low As Reasonably Achievable (ALARA) or As Low As Reasonably Practicable (ALARP) in the UK (Olden et al., 2018; Care Quality Commission, 2022).

1.1.3 Scanning techniques

If a CT scan is justified, then the dose should be optimised to keep the dose to the patient ALARP. The radiographer has direct control over some dose optimisation measures, and it is essential for them to carefully follow scanning techniques including checking that the patient is positioned correctly since this can have a bearing on the radiation dose (Kubo et al., 2014; Yabuuchi et al., 2018). The patient should be positioned in the isocentre of the CT scanner, which is defined as “the axis of rotation of the gantry” (Olden et al., 2018 pp 335). Most CT scanners have a meniscus shaped bowtie filter which reduces unwanted radiation dose to the peripheries of the patient and ensures the thickest part of the patient is irradiated by the most intense part of the

X-ray beam (Olden et al., 2018; Yang et al., 2019). If the filter is misaligned the peripheries will receive the intense part of the X-ray beam and the most attenuating part of the patient will receive a sub-optimal radiation dose resulting in increased image noise and unnecessary irradiation of the peripheral areas (Olden et al., 2018). When positioning a patient for a CT head scan, the head can be tilted to reduce the radiation dose to the lens of the eye. It can be reduced by 89% by tilting the head 17 degrees from the orbito-meatal line and reducing the scan range. This position can also reduce the dose to the salivary, mid brain and pituitary gland (Yabuuchi et al., 2018). Programming the scanner to move caudally cranially (to start at the bottom of the skull and move in the direction of the top of the skull) during the CT head scan can avoid irradiating other radiosensitive areas such as the thyroid because the extra field of view will just include the air above the head (Yabuuchi et al.,2018).

In CT scanning there is a balance between radiation dose and image quality with lower exposure potentially producing images with more noise (Martin et al., 2016; Demb et al., 2017). Radiologists, working with medical physics experts and radiographers need to decide on optimum exposures to produce clinically diagnostic scans (Demb et al., 2017). In projectional X-rays, if too much or too little radiation has been received by the image detector, the operator can observe this on the resultant image, but in CT scanning the image is reconstructed from the attenuation data received by the image detectors and there is not a direct relationship between the radiation exposure and the appearance of the resultant image (Vosper et al., 2021). Therefore, radiographers do not have a feedback mechanism by which to judge if too much or too little radiation has been selected although, measuring the contrast-to-noise ratio (CNR) can be a helpful to assess the image contrast (Chen et al., 2013).

Radiographers should carefully consider the scan length required when setting up for a scan, since reducing the scan length after checking the relevant anatomy is included in the field of view (FOV) is an effective way of reducing the radiation dose to the patient without any detriment to the image quality (Joyce et al., 2020). One study indicated that almost three quarters of patients' scans exceeded the anatomical area required in the Z-axis leading to extra radiation doses of up to 79% to specific organs (Botwe et al., 2021; EuroSafe, 2022). Ghoshal and Gaikstas (2021) recommended that when scanning patients for suspected renal colic, radiographers should start the CT scan on the upper border of the 11th Thoracic vertebral body after their study showed that only 10% of scans met the target of not ‘over scanning’ more than 10% above the highest kidney.

1.1.4 Technical approaches

Multi-sliced helical/spiral CT was developed in the 1990s, which shortened examination times. Currently images can be acquired from 64 to 640 slices. This along with a larger field of view, has led to an increase in the use of CT scanners especially for cardiovascular, brain and perfusion imaging (Yurt et al., 2019). Technical approaches by manufacturers have led to a reduction in patient dose while maintaining image quality.

The tube current (mA) combined with the X-ray tube rotation time, milliampere-second (mAs), has an effect on the radiation dose to the patient being directly proportional to the mAs, being the number of incident photons collected by the detector (Ibrahim et al., 2014; Vosper et al., 2021). Automatic tube current modulation (ATCM) was introduced by manufacturers to reduce the radiation dose to patients by adjusting the tube current automatically during scanning areas of high and low attenuation to obtain the maximum image quality using the lowest amount of radiation, tailoring the dose to the patient (Martin et al., 2016; Demb, 2017). ATCM is reported to have reduced the radiation dose by almost a third in arterial phase CT abdomen scanning when compared to using a constant tube current (Joyce et al., 2020; Yurt et al., 2019). ATCM can increase the tube current to dense areas of a patient such as a metallic implants and prostheses, resulting in higher dose to the area but because it adjusts exposures for other areas of the body such as the thorax it should still be used on these patients giving a net reduction in dose when compared to using a constant current (Foley et al., 2013). A more advanced ATCM has been developed and is known as Organ-Based Tube Current Modulation (OBTCM). Its aim is to reduce the radiation dose to the most radiosensitive organs such as breasts (Euler et al., 2016). Mussmann et al. (2021) evaluated three vendor’s OBTCM systems for anterior segment and total dose reduction with the maximum dose reduction 24% and 13% respectively when compared to not using OBTCM without an increase of noise in the image. One of the three vendor's systems increased anterior segment dose by 51% except at 100 kVp where no dose difference occurred.

When using ATCM, the radiographer is required to position the patient at the centre of the gantry because the centering has a bearing on the dose, causing variations of up to 41% if used incorrectly (Foley et al., 2013). Magnification occurs if the patient position in the gantry is the centre of the X-axis but not centred in the Y-axis, i.e. the table is too high or too low in the gantry, during the topogram/scout phase where the tube current variations are being calculated. If the patient is off-centred resulting in them being nearer to the X-ray tube then magnification will occur and the tube current calculations will be for a larger sized patient resulting in a higher radiation dose (Akin-Akintayo et al., 2019). Phantom studies have revealed that the magnification can be as much as 33% when the table height is positioned so it is closer to the X-ray source as opposed to being in the centre; this increases the tube current and automated tube potential when compared to the patient's real size, resulting in an increased patient dose (Filev et al., 2016).

Traditionally, the tube current has been reduced or modulated, but lowering the tube potential, kilovoltage (kVp), dramatically reduces the radiation dose because instead of a linear decrease, as with the reduction in tube current, the dose reduction is proportional to the square of the tube voltage reduction (Yabuuchi et al., 2018; Vosper et al., 2021). Moser et al. (2017) found that the dose could be reduced 30% by reducing the kVp from 120 to 100. If a high contrast scan is required the kVp can be lowered from 120 kVp to 80 kVp, this will enhance the bone and vessels especially if radiographic contrast media has been administered to the patient. A high contrast scan will not visualize the muscle and fat well, so is not used on a regular basis even though it reduces the dose to the patient (Yabuuchi et al., 2018). Lowering the kVp to 80 reduces the Compton scattering component of the X-ray beam and increases the photoelectric effect resulting in enhanced contrast (Ibrahim et al., 2014; Yabuuchi et al., 2018; Vosper et al., 2021). Moser et al. (2017) elucidate that the settings for changing the tube potential is not as flexible as tube current, since the setting are set in 20kVp increments, such as 80, 100, and 120 kVp, and that when a lower kVp is used the tube current often needs to be compensated due to the lack of photons reaching the detectors, causing image noise.

A large field of view 640 slice CT scanner is ideal for cardiac scans since it can scan the whole heart in a single rotation. This is reported to reduce the radiation dose to half when compared to the dose of conventional spiral scans, but this included advanced reconstruction of the images (Lu et al., 2019). The three main factors for estimating dose are: CT dose index (CTDI vol) which is the dose output from the scanner, dose-length product (DLP) which is the radiation dose over the whole scan and effective dose (E) which is a measurement of equivalent whole-body dose (Joyce et al., 2020). Abuzaid et al. (2021) compared the radiation doses from 4,16 and 160 slice scanners using the three main factors for estimating dose. They concluded that the 160-slice scanner had a lower radiation dose due to the higher number of detector rows.

Over ranging occurs in all spiral scanners; an extra half a rotation of the gantry occurs at the beginning and end of each scan to assist with the image reconstruction (Yabuuchi, 2018). An adaptive dose shield, consisting of collimator blades within the scanner, temporarily blocks the parts of the X-ray beam which are not used to create the image reducing the dose to the parts of the patient that are outside the field of view (Ibrahim et al., 2014). Tilting the patient's head for CT head scans can reduce over ranging effecting radiosensitive tissues (Yabuuchi et al., 2018).

1.1.5 Sequences and protocols

The main diagnostic imaging tool in oncology is CT scanning, being used for diagnosis, staging and follow-up; CT scanning is still used as an adjunct when MRI scanning is undertaken and contributes 49-66% of the patients' overall radiation dose. CT protocols need to be under constant review instead of using historical protocols or protocols copied across from previous scanners (Abuzaid et al., 2021). There needs to be a collaborative approach to set protocols, using the technical advancements developed and made available by manufacturers, which are reviewed and audited regularly. Kim et al. (2019) concluded that single phase CT could be used to image active bleeding in abdominal trauma instead of arterial phase, portal phase and a combined phase, reducing the patients' lifetime attributable risk (LAR) of cancer from radiation exposures. CT urology protocols for renal colic vary, with different institutions in different countries using between one to six phase; a single-phase protocol can significantly reduce the DLP and hence radiation dose to the patient (Gershan et al., 2020). Protocols need to be continually clinically reviewed and dose audit undertaken to compare local with national DRLs, to optimise dose and provide optimal clinical information (Razali et al., 2020; Granata et al., 2021).

1.1.6 Vulnerable Groups

Certain groups have increased LAR of cancer from CT scans, and there is a consensus of opinion that risks for adults from medical radiation exposures occur above or equal to 100mSv for multiple exposures over a short time frame (Brenner and Hall, 2012; Jeukens et al., 2021; Frija et al., 2021a). Kwee et al.(2020) explain that oncology patients with metastases who experience a reasonably long survival time are likely to have a disproportionate number of CT scans, defined as 40 or more in 10 years, to monitor response to therapy and surveillance. There is a non-negligible CT radiation induced cancer risk and mortality for patients who have a disproportionate number of CT scans, and this is particularly important with new therapies such as immunotherapy which are likely to increase the survival times of these patients (Friedlaender et al., 2019; Kwee et al., 2020; Jeukens et al., 2021). Frija et al. (2021a) found a small percentage of patients in Europe, 0.5% of the patients, had doses equal to or more than 100 mSv; most of them were oncology patients, but they discovered that there was variation ranging from 0-2.72% indicating that local practice or patient types contribute to the dose.

Children are a vulnerable group, and it has been demonstrated through epidemiological studies that young adults and children are more sensitive to the stochastic effects of ionising radiation (Brenner and Hall, 2012; Nagayama et al., 2018). Children and young people are likely to have a long-life span and therefore have an opportunity to receive a large cumulative dose of radiation especially if the exposure parameters are not adjusted for patient age and size (Brenner and Hall, 2012; Lee et al., 2016; Nagayama et al., 2018).

De Gonzalez et al. (2016) looked at the relationship between CT scanning and the risk of leukemia and brain tumours. They used these pathologies because they have a relatively short period between exposure and the induction of cancer. Pearce et al. (2012) demonstrated a positive association between cumulative doses in children of 50 mGy tripling the risk of leukaemia and doses of 60 mGy tripling the risk of brain cancer. Low voltage should be used for children because it reduces the energy of the photons providing sufficient energy penetration for children, as opposed to the number of photons which would occur if the tube current was reduced (Nagayama et al., 2018). Using an additional lateral scout view/topogram can check that the child is positioned correctly before the CT exposure takes place, reducing extra dose due to magnification and the bowtie filter (Filey et al., 2016; Peng et al., 2017; Olden et al., 2018; Yang et al., 2019). Doses from CT especially to children and young people should be kept ALARA, and alternative non-ionising radiation imaging technique should be used if appropriate (Pearce et al., 2012; Brenner and Hall., 2012; Lee et al., 2016). Recognising the potential damage from CT radiation dose, especially for children and young people, most countries have dose reduction bodies/ campaigns such as “Image gently”, “Image wisely” and” Eurosafe” to promote radiation protection (Brink and Amis, 2010; Goske, 2017; Frija et al., 2021b).

1.1.7 Reconstruction of Images

Using iterative reconstruction methods for reconstructing CT images can optimise dose while maintaining image quality since less dose is required to produce the same image quality as a scan without iterative reconstruction (Greffier et al., 2015). Lowering the tube potential can lower dose but increase noise in the image, however the iterative reconstruction algorithm can suppress the noise in the image (Nagayama et al., 2018). Whether to buy a CT scanner capable of iterative reconstruction and choosing to use it in a protocol is normally decided collectively by the radiologist, medical physicist, and radiographer.

1.1.8 Significant Accidental or Unintended Exposure Notifications

The Care Quality Commission (CQC) produce an annual report to improve compliance with IR(ME)R regulations, which reviews notifications and disseminates lessons learned to promote best practice (CQC, 2022). There have been several recurring themes: a disproportionate number of CT notifications compared to other ionising radiation notifications has been a recurring theme. Year on year the proportion of CT scan notifications has increased from 46% in 2017 when the thresholds for reporting CT notifications changed, to 72% in 2021 (CQC, 2018, 2021). In 2015, the inspectors pointed out that 22 million X-rays were performed and only 4.2 million CT scans, so it does not explain the disproportionate number of CT scan notifications (CQC, 2015). Another recurring theme is scanning the incorrect patient, through lack of a robust identification check; this accounts for a third of all the notifications as opposed to technical or operator errors which combined account for a third of all diagnostic radiography notifications (CQC, 2021). The CQC have commented on the lack of workforce and the inadequate training of the workforce, leading to a lack of capacity with the increased demand in CT and an increase of notifications (CQC, 2021). Meticulous justification of scan referrals is an effective way of reducing radiation dose, screening out unnecessary scans. Insufficient training of radiographers, after a new CT delegated authorisation protocol was introduced for justification, prompted an inspection by the CQC due to its importance as a safety issue (Joyce et al., 2020; CQC, 2021).

1.1.9 Collaboration

Riley et al. (2014) advocate that dose optimisation is best realised by an inter-professional team consisting of radiographers, radiologists and medical physics experts; this is a COMARE recommendation reinforced by the American Association of Physicists in Medicine" Image Wisely" campaign (2017) (Chell, 2016).

The UK department of Health have recognised the need for collaborative working and are working with relevant professional bodies to form 'image optimisation teams' to consolidate knowledge to optimise CT scans for dose and image quality at a local level (Chell, 2016). This multi-disciplinary team approach allows each professional group to learn from the expertise of the others and create an open environment to discuss the balance between patient dose and image quality. The 'image optimisation teams' consider technical advances that could contribute towards optimising dose; this improves the understanding of novel technical developments (Chell, 2016). The need for collaborative working to optimise CT scans has been recognised in Canada: a centre of clinical expertise in radiation safety has been set up to gather knowledge and communicate best practices related to the use of ionising radiation in a medical context, via a task force which travels around the country to visit CT departments (Nassiri et al., 2016). The Medical Exposures Group (MEG) was set up in 2013 in the UK to improve patient safety in medical exposures and has contributed towards the COMARE reports (Elliott, 2014), MEG are looking to expand onsite advice (Findlay et al., 2016). Some UK sites have already embraced the image optimisation team model and have found it to be effective and have actively promoted co-operation between professional groups for CT dose optimisation. The CQC (2021) continue to stress that the radiation protection framework requires a multidisciplinary approach.

For effective dose optimisation there needs to be a radiation protection culture within the department, which is a combination of knowledge, values, behaviours and experience among professionals and patients. A radiation protection culture is driven by the leadership, and staff require continued education and effective communication (Ploussi and Efstathopoulos, 2016).

1.1.10 How do radiographers learn to optimise dose in CT scanning

Effective dose optimisation in CT scanning depends on a foundation of evidence-based knowledge followed by practical skills and then a synthesis of knowledge to enable an understanding of the technical and educational factors' contribution to dose optimisation. The educational component is normally taught in the university, and some universities have a real or virtual scanner to allow for theoretical and practical training. The use of computer-based simulated (CBS) CT learning is currently limited and requires software developments to give it equivalent functions and capabilities as clinical scanners (Chaka and Hardy, 2021). Australian diagnostic radiography students felt the CBS learning allowed them to learn at their own pace and to make errors, but they found that they experienced technical difficulties; introducing facilitated learning instead of independent learning could have alleviated the technical problems (Liliy et al., 2020). The current model of undergraduate diagnostic radiography training is an effective method of teaching for entry level radiographers because it is based on Bloom's taxonomy and is the best educational model available (Mifsud, 2017).

Atherton (2013) explored a modification of Bloom's model that had the stages, starting at the bottom of the pyramid: remembering, understanding, applying, analysing, evaluating, creating. The remembering and understanding occurs in the academic environment, with applying, analysing, evaluating, and creating occurring in the clinical and educational environment. Westbrook (2017) illustrated that in MRI, the student radiographer experience is limited to basic theory followed by observation in the clinical department, and this holds true in other cross-sectional imaging modalities such as CT because the undergraduate course focusses on general radiography (Sloane and Miller, 2017). The training does not align to post-registration skills and competency requirements for cross-sectional imaging, and supplemental training is required post-qualification (Westbrook, 2017: Sloane and Miller, 2017).

1.1.11 Lack of staff

With the ever-increasing number of CT scans the imbalance between the supply and demand of staff is ever increasing. This is a worldwide problem reflected in the UK workforce (Nightingale et al., 2021). In 2016 the projected change in supply of NHS diagnostic radiographers included losing more than a quarter of the workforce for reasons other than retirement as well as 9% to retirement, 9% to vacancies and 5% moving from full time equivalent (FTE) roles to part time roles resulting in an estimated 15,070 workforce of diagnostic radiographers in 2021 (NHS England, 2017). Nightingale et al. (2021) suggests that work patterns with large workloads, long shifts with lack of flexibility contributed to attrition of radiographers along with lack of career progression and access to continuous professional development (CPD). Retaining radiographers in the workforce is vital for continuity, improving morale and allows an advanced workforce to build and take on roles, such as radiographer reporting. Newly qualified radiographers cannot move into roles created by experienced staff who have left the profession because they lack knowledge, training, and experience for those roles (Nightingale et al., 2021).

Diagnostic radiography is the largest professional group in the clinical cancer workforce and CT scans are used in many clinical specialties with increasing regularity, in 2016 it had a 101% fill rate of undergraduate courses but by 2021 England is still short of 4000 radiographers (NHS England, 2017; NHS England, 2020).

The College of Radiographers' career framework (2016) has been designed to help alleviate the workforce shortage by having two pre-registration roles of support worker and assistant practitioner roles and the newly introduced degree apprenticeship will contribute to the workforce (Health Education England, 2020; Society and College of Radiographers, 2021a). The demand for specialised and experienced radiographers is increasing since students, apprentices, assistant practitioners and support workers all need training and supervision by qualified radiographers. Newly qualified radiographers also require teaching and supervision until they feel competent to carry out the tasks required of them, which add to the demands of experienced staff who are under pressure in the workplace (Sloane & Miller, 2017; Society and College of Radiographers, 2021a).

Advanced techniques such as reporting need radiologist input; or for radiologists to work with the radiographers and clinical scientists to decide on the CT scanning sequences and protocols. The Royal College of Radiologists (RCR), (2021), is concerned that in spite of radiologists staying within the profession to help with the COVID-19 pandemic, the radiologist workforce is still 33% below its pre-COVID-19 level and requires 2000 radiologists for safe staffing levels. Furthermore, the RCR warns that by 2025 the shortfall will hit 44% without intervention. Three times as many consultant radiologists plan to leave the profession and half intend to cut their hours in 2022 (RCR, 2021). The RCR (2021) feels that the current training places for radiologists need to triple to provide a safe workforce of the future. With a career pathway of over 12 years to become a consultant clinical radiologist, even if the training places were available in 2022 the trainees would not become consultants until 2034 (RCR, 2019; RCR 2021). Although undertaking a CT scan can increase the survival rate of a patient, radiologists should be involved in any decision to use ionising radiation, but this becomes challenging with severe staff shortages (Roberts et al., 2013). Radiologists need to be trained and mentored so they can become competent in their role, yet this cannot happen with an unsafe level of radiologists.

The Institute of Physics and Engineering in Medicine (IPEM) (2018) feels that a lack of medical physicists contributes to longer waits for patients' scans, because medical physicists are required to support the safe running of scanners. They reveal that one in nine posts diagnostic radiology physics roles are vacant because of a shortage of recruits and retirement.

Radiographers, radiologists, and medical physicists need time to work together to set CT scanning protocols, decide on scanning sequences and optimise radiation dose for patients. With staff shortages this is difficult.

1.1.12 Knowledge and education

Student radiographers benefit from being taught via a variety of learning styles in academic and clinical environments, with an approximately fifty-fifty mix of environments in UK undergraduate programmes (Society of Radiographers 2021a).

Experiential learning is a type of learning from life experiences, and this is the type of learning that occurs in the clinical learning environment (CLE), which is a contrasting style to systematic learning which occurs in a traditional academic environment (Kolb, 2014; Westbrook, 2017). Experiential learning encourages deep learning because it allows the learner to discover, process and apply knowledge thus encouraging connections between theory and practice (Rong-Da Lang, 2021). Learning styles can play a part in how the learner learns and how the teacher teaches but Pashler et al. (2008) feel that assessment of learning styles during teaching is not required since they feel that there is no adequate evidence to support it and it could disengage learners who feel that they are not being taught in their style. In contrast, Fleming, and Baume (2006) advocate that learning styles are important because preferences are part of our makeup, and they inform how we approach things. By deciding which of the four learning styles: - visual, auditory, reading/writing, and kinesthetic - is the learner's preference, learning strategies can be aligned to the learner's style preference and this flexibility can enhance understanding and motivation whilst learning (Fleming and Blume, 2006). Rohrer and Pashler (2012) point out the widely held belief that teaching should fit students' individual learning styles but they feel that there is a lack of evidence to support teaching to accommodate students' individual learning styles. Hattie and Donoghue (2016) conducted a large-scale meta-synthesis to identify the most effective teaching and learning strategies. Hattie and Donoghue (2016) concluded that teaching should not be modified for individual learning styles, but subject content should be taught with a variety of learning strategies embedded within them to encourage deep learning. Subject content should be taught in an effective and comprehensible way with a variety of instruction methods (Rohrer and Pashler, 2012). Gudnason (2017) agreed explaining that just because teaching for learning styles was common it doesn't make the process pedagogy sound. Diagnostic radiography subject content is dynamic and suits all types of learners due to its variety of teaching strategies in a wide variety of environments.

An important aspect of learning in the clinical environment is psychological safety, which is a shared belief that it is safe to participate in risk-taking interpersonal activities in the workplace, such as saying what you think even though you know that your viewpoint is not popular (Edmondson & Lei, 2014). It is difficult as a student or new member of the staff in the clinical environment to experiment with new approaches to CT dose optimisation, building on their prior academic knowledge, because they may not feel safe to do so because the environment is not psychologically safe (Newman et al., 2017). Edmondson (1999) explained a psychologically safe learning environment to be one where employees feel safe to feedback, voice their opinion, collaborate, take risks and experiment, which is the ideal environment for radiographers to learn in. The challenge in the healthcare setting is that high-quality care for the patients means that there is a system of professional standards, high-level accountability, and organisational structure making psychological safety appropriate but also hard to achieve (Edmondson et al., 2016). The social hierarchy within the profession can be a challenge to students and newly qualified radiographers who are unable to contribute to discussions (Naylor et al., 2015; Cowling and Lawson 2020). Teaching in the clinical environment can be unplanned and taught by radiographers who have learned from their peers, leading to misconceptions being cascaded and preserved. This is a particular challenge with advancing technology, leading to a lack of ability to make connections between theory and practice (Westbrook, 2017). Westbrook (2017) findings relate to magnetic resonance imaging (MRI) but also holds true for other cross-sectional imaging such as CT; Sloane and Miller (2017) support this view.

In their career, healthcare professionals will be shaped by culture, education, and organisational socialisation which enables them to be competent in specialised adaptations to perform the skills required in the clinical environment (Kolb, 2014).

1.1.13 Social Interactions

Teaching and learning in the clinical environment can be challenging because of the balance between emotions of self, patients, and teacher/learner with all their complications (Mosca, 2019). Radiographers need to be able to monitor their own and other people's emotions, and emotional intelligence (EI) traits are likely to have an influence on interactions with patients and staff (Mackay et al., 2015). Emotional intelligence is sometimes known as emotional-social intelligence and described as a synthesis of social and emotional proficiencies, skills and actions that enable people to understand themselves and others, how to relate to them and cope with the environment around them (Clearylet al., 2018). Petrides and Furnham (2003) developed the emotional intelligence theory to include traits and developed a tool to measure them. Mayer et al. (2008) argue that this is a mixed model and some of the EI traits are elements of social intelligence. Petrides (2009) developed the Trait Emotional Intelligence Questionnaire, which measures EI as self-reported personality traits. This questionnaire has been used extensively and in its short form measures wellbeing, self-control, emotionality, and sociability as well as giving a global EI score. EI is very important in radiography because senior staff tend to suffer from emotional exhaustion caused by stress in the workplace, with the main contributing factors being workloads and staff shortages (Nightingale et al., 2021). Trying to learn from emotionally exhausted staff, while caring for patients, requires a high level of emotional intelligence and mature social skills (Lee et al., 2019; Lartey et al., 2021). Chipere et al. (2020) looked at how to improve the workplace for newly qualified radiographers and formulated four main concepts: interpersonal relations are crucial in the clinical environment, integration only occurs with good levels of support, new employees need to be integrated into the department and the clinical environment must facilitate learning. Clinical supervision according to Proctor's three function model should include, formative (skills development, increasing knowledge), normative (professional standards, managerial aspects) and restorative (emotional support) functions to deliver effective clinical supervision (Butterworth et al., 2005; Health Education England, 2019).

1.1.14 Operator dependence in CT dose optimisation

Dose optimisation is dependent on a combination of factors. The evidence suggests that the resultant radiation dose can be directly dependent on the radiographer but also dependent on protocols which should have been agreed by a multi-disciplinary team. Radiographers can decrease the radiation dose to the patient by challenging justification, setting the scanner to scan the required field of view only, positioning and centering the patient correctly, and adjusting the kVp for the patient, which is particularly important for vulnerable groups. Radiographers do not work in isolation and should work collaboratively to set scanning parameters. Radiographers require effective training which encourages continuous professional development and lifelong learning to keep abreast of technical developments in CT scanning. The lack of staff and the increase in the number of CT scans has made dose optimisation in the department challenging, especially as social and educational factors have a part to play in radiation protection culture. Figure *1.2* shows a visual representation of the educational, clinical, and social factors involved in CT dose optimisation.

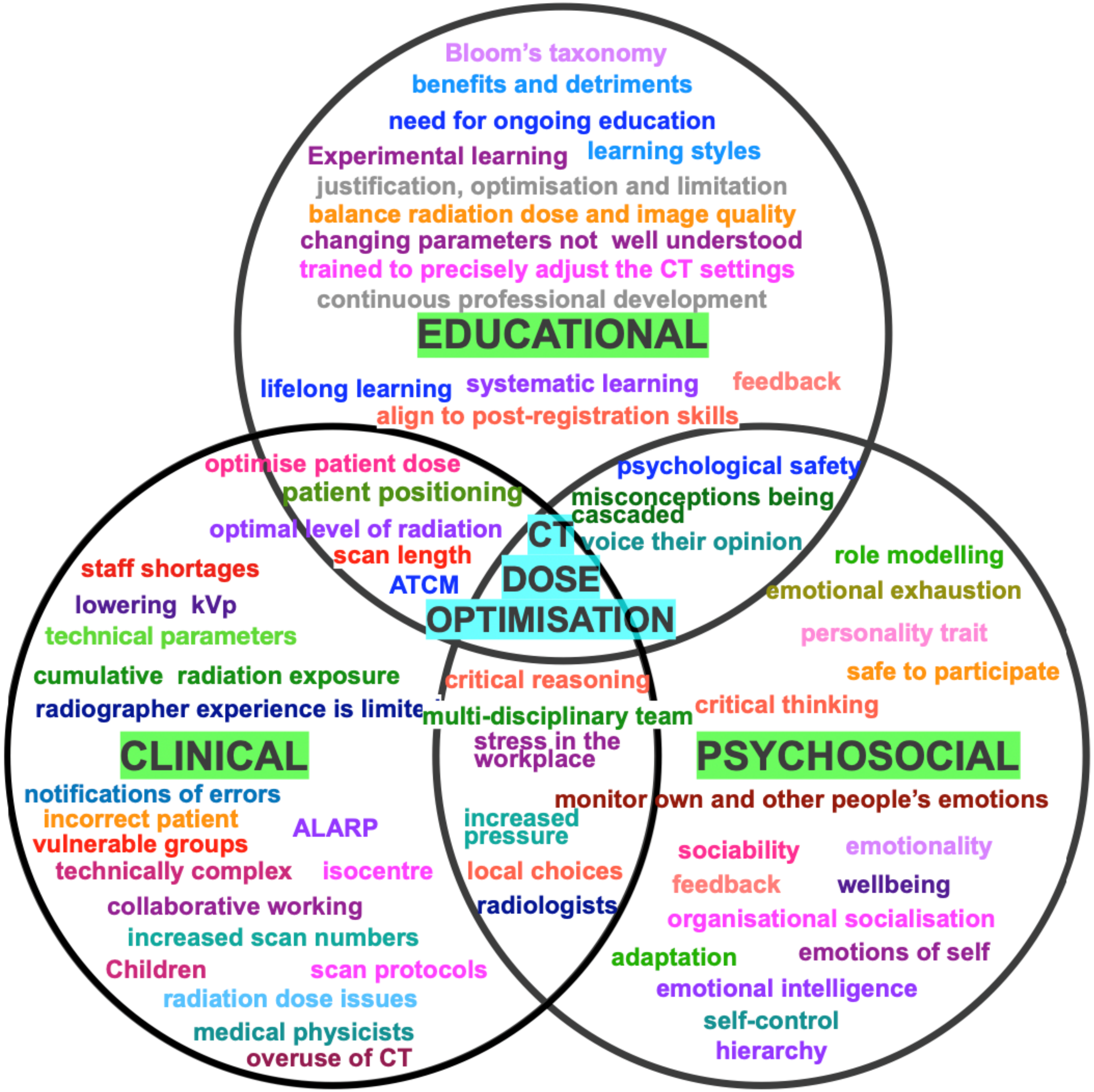

Figure 1.2 - *Venn diagram of factors contributing to CT dose optimisation*

Chapter 2- The theoretical framework

2.1 Formation of the theory

In response to the recent literature regarding CT dose optimisation, this study sets out to explore the complex relationships between clinical, social, and educational factors and CT dose optimisation, which is described pictorially in Figure 1.2.

CT scanning is not perceived to be as operator dependent as other imaging modalities such as ultrasound, but to achieve CT dose optimisation relies on radiographers to position the patient correctly and to select the correct scan length, since these have a considerable impact on the radiation dose if incorrect (Gummadi, 2018; Joyce et al., 2020). Radiographers need a good working knowledge of cross-sectional anatomy as well as radiation protection; they are required to synthesise their foundation knowledge in these subjects to provide the optimal dose for the patient in CT scanning.

CT scanning contributes disproportionately to the radiation exposure of patients when compared to other ionising radiation-based imaging modalities and this can lead to notifications of doses much greater than intended, with worse cases leading to deterministic effects as well as stochastic radiation side effects (CQC, 2022; Elliott, 2014). There is a year-on-year increase in notifications involving CT scanning (CQC, 2022).

Epidemiological studies have revealed that there is a cumulative effect from CT scans which can induce cancer in vulnerable groups, who either receive a large number of scans in a short timeframe, or children or young people who have a long life expectancy (Nagayama et al., 2018; Brenner and Hall, 2012). There is a consensus from learned bodies that CT scanning has detrimental effects and should therefore only be undertaken by trained operators and that there should be a multi-disciplinary team to set scan parameters (Chell, 2016). The variation in CT doses across countries is attributable to local choices regarding technical parameter (Smith-Bindman, 2019).

Investment is required in pre- and post-registered radiographers to empower them to work safely and effectively in the clinical environment with the demands for increasing number of scans and increasing staff shortages (Nightingale et al., 2021; NHS England, 2020). The staff shortages can add to the pressure of work for radiographers leading to emotional exhaustion and therefore leading to an inability to teach objectively with an atmosphere of psychological safety (Edmondson et al.,2016). Investment is required in teaching for both trainees, newly qualified and experienced radiographers to allow radiographers to keep up-to-date and competent in this rapidly advancing technical modality (Sloane and Miller, 2017). Pre-registration radiographers require extensive experience in CT scanning to become competent and carry out experiential learning to build on their educational foundation (Sloane and Miller 2017). There is a feeling that undergraduate courses are not aligned with cross-sectional imaging requirements and that regular updates are required for qualified staff to remain competent and be supported in their learning, so they can teach others (Westbrook, 2017). At the end of an undergraduate course post-registration radiographers may feel that they are unable to meet the graduate attributes of being able to perform a CT head scan with their current training (Sloane and Miller, 2017).

Social factors play a part in how people learn and interact in the clinical environment, there needs to be consideration to the extent and influence of these factors (Berkhout et al., 2015). This study sets out to establish which social and educational factors in the clinical environment have an influence on radiographers training regarding CT dose optimisation before and after qualification.

2.2 The aim and objectives of this study

The Aim is to identify training requirements for UK CT radiographers regarding specifically social, clinical, and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation.

The objectives are to:

- systematically review methods of training and education to identify the most appropriate method for optimised CT scanning in the clinical environment
- systematically review models of technical skills training from other professions and assess if they are transferrable to optimisation of CT scanning

- systematically review how CT skills training and education can be delivered in the clinical environment
- systematically review social education and social interactions within the CT modality and to what extent these affect education
- explore radiographers' knowledge of exposure parameters and view on education using a cross-sectional methodology
- using a longitudinal study explore pre- and post-registration radiographers' knowledge and experience of dose optimisation within CT scanning
- using a longitudinal study measure pre- and post-registration radiographers' emotional intelligence
- using a longitudinal study explore the radiographers' educational experience
- using qualitative methods to explore advanced CT radiographers' (focus group), medical physics experts and radiologists (semi-structured interviews) expert opinions
- using appropriate methods of analysis compare and contrast data with evidence base
- discuss combine and contrast emerging themes in a discursive chapter
- document the findings accurately and coherently for dissemination.

2.3 The research question

Through evaluation of radiographers' views, experiences and perspectives using mixed methodology, what are the factors that will contribute to holistic dose optimisation within the clinical environment?

Chapter 3- Methodology

3.1 Conceptual overview

The overall research is a sequential mixed methods study, consisting of three linked convergent parallel methods[1], integrating, and connecting quantitative and qualitative data, preceded by systematic reviews. The mixed methods consisted of a cross-sectional survey, a longitudinal study and expert opinion via qualitative methods, as shown in Figure *3*.1

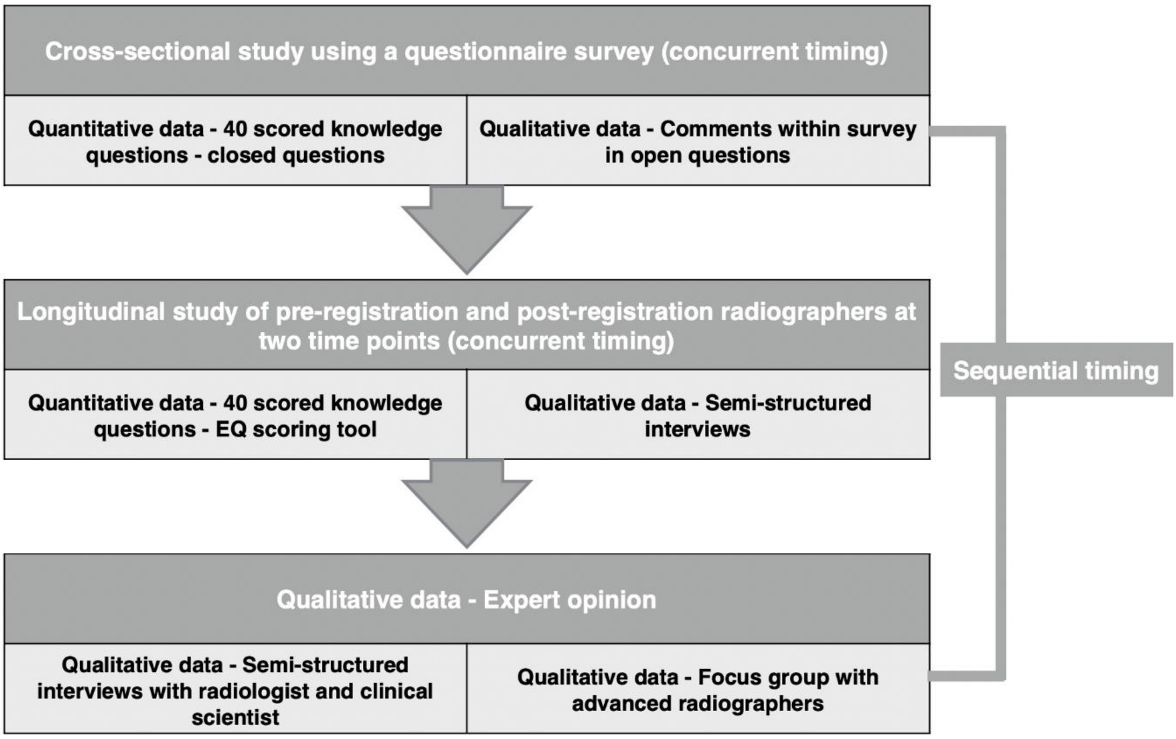

Figure 3.1 - *Schematic diagram of the research design*

The systematic reviews gave an in-depth analysis of current literature using rigorous method to investigate training and education for CT scanning in the clinical environment from an educational and social perspective.

The cross-sectional survey and longitudinal studies used parallel mixed methods with concurrent timing, acquiring both sets of data at the same time in a single study

[1] Convergent parallel methods are the simultaneous collection of qualitative and quantitative data.

(Johnson et al., 2007). Quantitative and qualitative data from the survey were treated independently during data collection and analysis. The results were combined to provide breadth and depth of understanding to inform the next stage and the strands were used to triangulate themes (Tashakkori and Teddlie, 2021). The longitudinal study explored pre- to post-registration radiographers' views of education, their emotional intelligence, and how knowledge and experience of CT dose optimisation in the clinical environment changed over time. Expert opinion was sought by participation in focus groups and semi-structured interviews by specialists in the last strand of the study using qualitative methods. The resultant synthesis at each stage mixed and merged results from the strands to give an overall interpretation. The final synthesis used elements from the three strands (Johnson et al., 2007).

3.2 Participants

The three phases of the study involved the recruitment of three different populations. Participant information sheets were given to all the groups in advance to allow informed consent. Ethical approval was sought and approved by the university ethical committee, for each of the three phases of the study. All participants were over 18 years old.

The cross-sectional survey involved the recruitment of UK CT radiographers by self-selecting sampling[2]. The study was advertised in the monthly professional journal, and website of the Society of Radiographers. Qualitative and quantitative data were obtained from a questionnaire for this phase of the study.

For the longitudinal study, participants were recruited from the final year of a BSc Diagnostic Radiography and Imaging course. Information about the study was given to the cohort of potential recruits at the end of a lecture. Participants were self-selecting. The 14 recruits, now post-registration radiographers, were followed up eighteen months later for the second part of the longitudinal study. The second part of the longitudinal study occurred two years after the first part. Qualitative and

[2] Self-selecting sampling is a non-probability technique where participants volunteer to participate in the study.

quantitative data were obtained from questionnaires and in-depth interviews at two timepoints.

For the final phase of the study participants were advanced CT radiographers, radiologists, and clinical scientists, who were purposively sampled[3]. Expert opinions were obtained by conducting focus groups and in-depth interviews. This phase provided qualitative data.

Before qualification the radiographers in the longitudinal study will be referred to as 'student' or 'pre-registration' radiographer, after qualification the 'student' or 'pre-registration' radiographer will be referred to as 'post-registration' radiographers. Pre- and post-registration radiographers are the same cohort of participants.

3.3 Frameworks of Mixed Methods Research

This section explains the characteristics of mixed method research (MMR), justifies the use of MMR in this study and explains how it is integrated into the study design. MMR can be useful in health sciences when complex phenomena are studied (Kidd et al., 2011). Creswell (2015) identifies MMR as an approach to research where both quantitative and qualitative data are collected and then integrated to allow the researcher to draw interpretations based on the combined strengths of both sets of data. MMR is a general term, studies collect the quantitative and qualitative data at points within the research, not necessarily at the same time point, and they may or may not have equal weighting.

MMR is not simply adding qualitative data to a quantitative study or vice versa, it requires careful design with well-founded rationale. Using a framework in the study design produces a robust system with clear aims before any data is collected (Creswell, 2021).

Different strands in the design should be considered. There are many strands which in a combination provide a framework for the study making each mixed method study

[3] Purposive sampling is non-probability sampling with participants recruited for their characteristics and for the objective of the study.

different, with such a choice of permutations making one mixed method study very different from another mixed method study (Clark and Ivankova, 2015). The integration of qualitative and quantitative approaches in MMR requires a robust framework to enable precise design and valid interpretation, Figure 3.1 shows the framework for this study with three strands. MMR can lead to a more comprehensive understanding of the subject than just one approach and is an expansive and creative form of research (Johnson et al., 2007). Triangulation[4] between the two approaches leads to validation of data through cross verification providing a powerful form of analysis (Natlow, 2020).

Since its inception a quarter of a century ago, MMR has evolved with common elements but there is some disagreement about the core meaning of the approach. Creswell (2015) describes MMR as a method not a methodology, whereas Tashakkori and Teddlie (2021) have an alternative view describing the combination of qualitative and quantitative approaches as mixed methodology. There is a methodology debate which has three positions, quantitative, qualitative, and mixed methods (Askarzai and Unhelkar, 2017). Some believe this debate can be traced back to Greek philosophy where belief in singular or universal truths was endorsed by Plato and Socrates whereas Sophists believed in multiple or relative truths (Johnson et al., 2007; Askarzai and Unhelkar, 2017). Johnson et al. (2007) position MMR in-between Plato (quantitative research) and the Sophists (qualitative research) being a middle solution for many research interests (Askarzai and Unhelkar, 2017).

A paradigm is a philosophical way of thinking, adapted from the Greek word for pattern and introduced by Kuhn in the sixties (Kivunja and Kuyini, 2017). A paradigm consists of five components which are, ontology, epistemology, axiology, methodology and rhetoric. Ontology is how reality in the world is seen, epistemology is how we know what we know, axiology is how the roles of values are viewed, methodology is how the procedures of research are conducted, and rhetoric is how language is used in the research (Cresswell, 2007; Kivunja and Kuyini, 2017; Askarzai and Unhelkar, 2017).

Johnson et al. (2007) argue that the primary philosophy of modern MMR is pragmatism with an ontology of diverse viewpoints, interpreted from the possibility of action with

[4] Triangulation is the use of multiple data sources to answer the research question.

both subjective and objective epistemology. Pragmatism is real-world practice which is problem centered, pluralistic and sets out consequences of actions (Cresswell, 2007). Kumar (2018) feels that mixed methods does not have a discrete paradigm as opposed to the two main paradigms qualitative and quantitative approaches which are the foundation of research methodology. MMR can use other paradigms, although it has been criticised for mixing incommensurate paradigms because quantitative and qualitative research is underpinned by different assumptions about ontology and epistemology (Dures et al., 2011). Researchers using MMR should have the freedom to use the qualitative and/or the quantitative methods to match the beliefs that underpin their research and therefore as well as pragmatism the worldview could be used, which could include constructivism, post-positivism, and advocacy (Cresswell, 2007; Dures et al., 2011).

Multiple paradigms can be used in a study, applying them to different research questions within the study. The paradigms should be clearly identified and separated from each other (Gorard and Taylor, 2004; Sale and Brazil, 2004). MMR combines paradigms making it an adaptive form of research with a fluid framework.

Positivism was first used by Comte in the early nineteenth century, promoting scientific thought with independence between the researcher and the participants providing empirical evidence (Hammersley, 2019). Post-positivists argue that the researcher has an influence over the participants, and they are investigated contextually (Panhwar et al., 2017). Post-positivism is looking for the truth but acknowledges that it is difficult to get there (Panhwar et al., 2017; McMurtry, 2020). Post-positivism is useful in mixed method research because it investigates the phenomena in an objective way and it can be applied to quantitative and qualitative research, but its emphasis is on the quantitative component (Panhwar et al., 2017).

The constructivist approach mirrors learning in clinical practice, being active not passive. In education constructivists believe that human learning is constructed on building new knowledge on a base of previous learning with the foundation learning being delivered in the university (Bada and Olusegun, 2015). If learners encounter a new learning experience which conflicts with their current understanding, their understanding can change to accommodate the new experience. Learners remain active in this process applying current understanding and include relevant elements in new learning experiences, judge their relevance/validity of prior and emerging knowledge, based on that judgement they can modify knowledge (Bada and Olusegun, 2015).

Johnson et al. (2007, p.113) suggest that MMR is “an approach to knowledge considering multiple viewpoints, perspectives, positions and standpoints”. MMR has the quality of being real-world practice orientated which supports the genre of health-sciences with its problem centered ideology (Cresswell, 2007). MMR can be a very powerful methodology resulting in an in-depth investigation merging data from two sources, to provide a robust interpretation of the data (Kumar, 2018). Qualitative and quantitative data can agree reinforcing the result of the investigation and sometimes the two paradigms can produce conflicting results. There is a potential for a continuum of everything in-between, a perfect match and a complete mismatch when interpreting MMR data (Kumar, 2018; Creswell, 2021). Using MMR can produce strength of data or further issues to explore.

Being an MMR researcher involves an in-depth knowledge of both qualitative and quantitative study design, analysis, and interpretation as well as knowledge of how to combine data and interpretation of the integration. For a lone researcher such as a PhD student this is an onerous task, but for a research team this can be easier drawing on skills from several members of a team. The use of rigorous qualitative and quantitative methods is paramount to produce valid MMR. Ideally, the quantitative and qualitative components should be equal or at least each component should be large enough to represent its approach (Creswell, 2021). In practice one component may be much greater than the other but one method should not just be added on as an afterthought. MMR was used in this study because it was felt that neither quantitative nor qualitative research alone would be sufficient. It was felt that a combination of both approaches would lead to a more in-depth understanding of the research question (Clark and Ivankova, 2015).

A parallel (convergent) design was used for the surveys with both qualitative and quantitative data being considered equal importance (Clark and Ivankova, 2015; Creswell, 2021). The design was useful in this study since questionnaires are time limited, synthesis occurred post collection and led to the formulation and content of the semi-structured interview questions for the pre- and post-registration radiographers by revealing relevant topics at a national level.

The expert opinion phase of the study used themes identified in the cross-sectional and longitudinal study which were discussed at focus groups and semi-structured interviews to provide triangulation.

3. 4 Quantitative components

Data was collected from qualified UK radiographers in the national cross-sectional survey. Data was collected a two timepoints in the longitudinal study, as a final year student and two years later as a post-registration radiographer. Quantitative data were collected using a national cross-sectional survey, questionnaires on CT exposure parameters, and an emotional intelligence tool in the longitudinal study. The CT exposure parameter questionnaire (Foley et al., 2013 (Appendix 1)) and emotional intelligence tool (Petrides, 2009 (Appendix 2)) were validated via publication in peer reviewed articles. Results were analysed via descriptive statistics and the scores in the cross-sectional survey were compared to the scores in the original published data by Foley et al. (2013), which included scores from European CT specialist radiographers and radiologists.

In the longitudinal study the participants completed the CT exposure parameter questionnaire and an emotional intelligence tool at each of the timepoints giving a repeated measure design. The scores of the pre- and post-registration radiographers were compared with the results of the radiographers in the cross-sectional survey.

Each set of data from the CT parameter questionnaires was tested for normality using the Kolmogorov-Smirnov Test of Normality, t-test for independent means or paired t-test, Cohen's *d* effect calculation and Power calculation (Cohen, 1992; Faul et al., 2009; Samuels and Marshall, 2013; Stangroom, 2021).

Continuous quantitative data were acquired. The correct statistical tests should be used to avoid statistical errors (Gerald, 2018). To make a statistical inference several assumptions about the data must be made, the first being that the distribution of the data is normal (Yazici and Yolacan, 2007). Normality tests compare the scores in the sample to a set of scores that are normally distributed with the same mean and standard deviation (Ghasemi and Zahediasl, 2012).

Ghasemi and Zahediasl (2012) recommend the Kolmogorov-Smirnov test of normality for symmetrical distributions with same sample sizes. The Kolmogorov-Smirnov test of normality is the most popular test of normality, but it should only be used for appropriate circumstances, such as small sample sizes, due to its low power (Yazici and Yolacan, 2007). The numbers in this study were small, so the Kolmogorov-Smirnov test of normality was an appropriate test to use. The sample size for cross-sectional survey was 47, and for the longitudinal study 14 pre-registration radiographers and 7 post-registration radiographers.

There are two types of statistical tests for comparing means, these being parametric and non-parametric tests (Mircioiu and Atkinson, 2017). Parametric tests are used for comparing means of normally distributed data, whereas non-parametric tests compare data that are not normally distributed or using ordinal data (Gerald, 2018). The t-test for independent means is a parametric test and was used for these data because they were normally distributed. There were two groups, pre- and post-registration radiographers, the groups matched being the same group at two timepoints, these were compared with paired t-test. The t-test for independent means was used to compare the results of the pre-registration radiographers with the national group of experienced radiographers and then the post-registration radiographers with the national group. The null hypothesis was that there was no difference between the groups (Scott and Mazhindu, 2014).

t-tests use degrees of freedom as opposed to the actual sample size, giving an effective sample size. Degrees of freedom are the number of pieces of independent information that can be freely varied without breaching any given restrictions (Eisenhauer, 2008). A small sample size will be less accurate than a large sample size, in a t-test with a low degree of freedom will be more spread out than one with a higher degree of freedom.

With small sample sizes the power of the ability of the statistical test to give a significant result becomes smaller. The data were put through a power analysis calculator to compute power (Faul et al., 2009; Scott and Mazhindu, 2014;).

A paired t-test was performed on the longitudinal study for the pre- and post-registration radiographers because this became a repeat measure design, giving less error because using the same participants removes the error of using different groups because of the variation in response from the two different groups is removed (Scott and Mazhindu, 2014). Cohen's d calculation was determined by calculating the mean difference between two groups, which have a similar standard deviation, and then dividing it by the pooled standard deviation (Stangroom, 2021).

3. 5 Qualitative method frameworks

The qualitative paradigm differs from the quantitative, using words as data as opposed to numbers. Rich but narrow data are obtained in qualitative research from complex intricate and detailed accounts from a few participants (Braun and Clarke, 2013). Qualitative data is collected in context at a local level, valuing personal involvement which is sometimes able to be generalised to a greater audience contributing to a theory of understanding (Ormston et al., 2014). Quantitative studies have fixed methods, seeking to identify relationships between variables creating shallow but broad data with objectivity (Braun and Clarke, 2013). Qualitative methods are less fixed than quantitative ones and a method can accommodate a shift in focus in the same study. Thematic analysis identifies pattern within qualitative data (Braun and Clarke, 2013).

This study is a mixed-method study so benefits from qualitative and quantitative insights. To generate consistency, the same method was used to analyse the qualitative data in the three data collection points in this study, the online survey, longitudinal study, and focus groups and interviews.

Once the data had been obtained from the three data collection points in the study qualitative data frameworks were assessed to decide which model would be the best fit for the data. The data represent radiographers undertaking CT scanning in the UK, although being qualitative data the sample sizes are small. The methods used to gather data varied, in the national survey the quantitative data was dominant, the qualitative data being obtained from written comments within the survey. The national survey was able to reach many participants and was available via an online link publicised by the College of Radiographers in the monthly journal distributed to all. A hard copy version was distributed to increase the response rate. The longitudinal study had face-to-face interviews at two time points, two years apart and aimed to capture the growth of a radiographers' knowledge and understanding of CT dose parameters from pre- to post-registration as well as social factors influencing their work in CT departments. The data collected in the longitudinal study informed the questions to be asked in the focus group and interviews with specialists, as well as generating themes. The third collection of data involved a virtual focus group and semi-structured interviews to obtain data from experts. The focus group process enables participants to identify and clarify their views more easily than in an interview setting (Tausch and Menold, 2016). Cyr (2016) believes that focus groups generate three types of data: individual, group, and interaction, providing rich data. In this study the focus groups helped provide triangulation and saturation[5] by specialists discussing the themes revealed from the earlier strands of the study.

Qualitative research is used widely in health, psychology, and educational research so frameworks from these disciplines were studied. The data analysis of the qualitative element of this research is a content driven, exploratory approach with the codes being derived from the data and not being predetermined as opposed to

[5] Saturation is the point in time when collection of data no longer changes the coding since each collection of qualitative data produces previously discovered data.

confirmatory, hypothesis driven research (Guest et al., 2012). The qualitative component of this study was conducted using the thematic analysis method of Braun and Clarke (2021). Thematic analysis is widely used in qualitative research as a method of analysis although it has been considered poorly differentiated from other research methods and not always recognised as a discrete approach (Braun, and Clarke, 2021). A lack of strict guidelines to undertake thematic analysis can lead to thematic analysis being confused with content analysis (Xu, and Zammit, 2020). Vaismoradi et al. (2013) felt that the boundaries were perceived as blurred. They clearly defined the differences in: the aims, the philosophical background, and the analysis process, leading to two separate qualitative designs. Descriptive phenomenology, content analysis and thematic analysis are part of the qualitative design continuum and are associated with a relatively low level of interpretation, whereas grounded theory or hermeneutic phenomenology are associated with more complex interpretation (Vaismoradi et al., 2013).

Qualitative research approaches have underlying philosophies. Phenomenology is characterised as studying several people with a shared experience, focusing on understanding the intrinsic nature of their subjective experience and suited to describing the essence of a lived phenomenon (Creswell and Poth, 2016). Phenomenology is from the discipline of psychology and philosophy and is from the domain of lived experience (Korstjens and Moser, 2017).

Grounded theory is a systematic theory developed from the data after the coding process, focusing on building theories of social phenomena from the views of the participants (Creswell and Poth, 2016). Grounded theory is from the domain of social settings and the discipline of sociology (Korstjens and Moser, 2017).

Hermeneutic phenomenology focuses on the lived experience of the participants in their own environment (Suddick et al., 2020). There has been an increase in hermeneutic phenomenology being used in health and social care and is from the lived experiences domain (Crowther and Thomson, 2020).

The philosophical background of both thematic analysis and content analysis has a factist perspective, being more or less accurate or true than the existing data, with the research finding out about real behaviour, attitudes or motives of the participants (Vaismoradi et al., 2013).

Vaismoradi et al. (2013) explain that content analysis has a communication theory background, to clarify the fundamental assumptions of content analysis. This view is not widely endorsed by others, and some describe it as atheoretical (Bengtsson, 2016; Braun and Clarke, 2021). In contrast, thematic analysis can be described as lying between a post-positivist approach, and the more interpretive focus of social researchers. (Kiger and Varpio, 2020). Thematic analysis is particularly suited to constructivism because during the process of analysis it can illustrate how certain social constructs develop (Kiger and Varpio, 2020).

Constructivism, with roots in education, philosophy, sociality and education, is based on observation and scientific study with constructivists learning through constructing their own understanding to make sense of the world using experience and reflection (Bada and Olusegun, 2015). Braun and Clarke's (2021) flexible method in thematic analysis involves a constructivist epistemology.

Vaismoradi et al. (2016) further describe qualitative content analysis and thematic analysis as qualitative descriptive design, focusing on description of the content and less on reflection and therefore its suggested meaning. Braun and Clarke (2021) have tried to redress the criticism by constantly reviewing their implementation process. Their model is straight forward and therefore widely used in qualitative research (Xu, and Zammit, 2020).

3. 6 Adopted methods of qualitative analysis

Four main types of thematic analysis are: template analysis, Braun and Clarke's thematic analysis, matrix analysis and framework analysis (King and Brooks, 2021). The main thematic analysis types are compared in Table 3.1. Framework, matrix, and template analysis are examples of codebook analysis. Template analysis involves more meticulous detailed coded analysis than framework or matrix analysis, often coding to four or more levels (King and Brooks, 2021). Template analysis has a high degree of structure, refining and redefining data but still has flexibility (Brooks et al., 2015). Framework analysis is used in social science; it is a method of analysis, not a research paradigm (Ward et al., 2013). Framework analysis is conducted via a table with each participant being allocated a row of the matrix and each sub-theme being given a column. This allows researchers to analyse the data without viewing the raw data (Kiernan and Hill, 2018). Matrix analysis is useful for large studies with large amounts of data. This analysis needs to be tabulated to show the interdependencies, connections, and comparisons across different levels of data giving a broad-brush approach (Burton and Galvin, 2018). In Braun and Clarke's (2021) thematic analysis there is, "a six-step implementation process for data development, coding and theme development: 1) data familiarisation (with notes); 2) systematic data coding; 3) generating initial themes from coded and collated data; 4) developing and reviewing themes; 5) refining, defining and naming themes; and 6) writing the report providing structural scaffolding "(Braun and Clarke, 2021 pp. 331). Braun and Clarke's thematic analysis uses data in a more bottom-up analysis rather than focusing on producing a codebook (King and Brooks, 2021). After an initial review of the data of this thesis, it was felt that Braun and Clarke's thematic analysis framework was the model that matched to the data, since the study did not involve many participants and flexibility was required to identify the themes from the acquired data. The thematic analysis process is not a linear one, there are basic precepts which can be applied flexibly in a recursive manner moving between the phases to suit the data (Creswell and Poth, 2016).

Table 3.1 – *Comparison of the four main types of thematic analysis*

Type of analysis	**Codebook**	**Meticulous detailed coding**	**Tabulated**	**Six-step analysis**	**Bottom-up analysis**	**Useful for large studies**
Braun and Clarke's thematic analysis	No	No	No	Yes	Yes	No
Template analysis	Yes	Yes	No	No	No	Yes
Framework analysis	Yes	No	Yes	No	No	Yes
Matrix analysis	Yes	No	Yes	No	No	Yes

3.6.1 Application of Braun and Clarke's (2021) six-step implementation process in this study

Data familiarisation and writing familiarisation notes

The verbal data were transcribed and checked against the audio recordings and written notes for accuracy. The transcriptions were read repeatedly in an active way to achieve immersion and familiarisation. The experience of transcription of the verbal data provided familiarisation with the data. Using recording software, ALCON Dictaphone, the recordings were able to be slowed down to 0.5 times the recording speed. The best play back speed was 0.8 times the recording speed; this kept the features of the participant's speech while allowing enough time to type the words. Some researchers feel that typing the transcript is a key phase of data analysis since it reinforces interpretive skills within the methodology (Saldaña, 2021). The typing is considered more than a mechanical act as the repetition of the transcription can create meaning within the data as it is interpreted and documented (Tessier, 2012). The transcriptions were time consuming and needed a high level of concentration to reproduce verbal communication verbatim. Listening to the recordings had the ability to mentally transport the researcher back to the time of recording, immersing them in the environment of the interview or focus group (Doody et al., 2013).

The pre-registration interviews in the longitudinal study, the focus groups and the face-to-face interviews were transcribed by the researcher but due to time constraints the initial transcripts from the post-registration interviews were typed by a trusted university translation service to produce draft transcripts. The researcher listened to the recordings and compared them to the draft transcripts along with the field (contemporaneous) notes to prepare the detailed final transcripts. The transcripts were printed in hard copy so the contemporaneous notes could be added so nonverbal nuances were included in the final transcript. After reading through the transcripts several times marking-up began and this was the beginning of generating initial codes.

Codes need to be generated systematically across the entire dataset beginning with initial codes and resulting in developing themes, a system of coding needs to be created to ensure rigour and reliability (Gale et al., 2013). The coding system invented needed to be repeated over four collections of data at different time points using different collection techniques, so a robust and reproducible system needed to be created. All the data were coded by the researcher reducing any variability due to different people coding. Analysis of the content occurred by the researcher generating the initial codes by noting any elements that appeared interesting to the reader, the initial codes are semantic codes identifying the direct surface meaning of the data not exploring beyond the words the participant said (Tian and Robinson, 2014). The coding scheme involved analysing in an inductive bottom-up approach as opposed to a theory driven top-down approach, so the codes can be generated from the data collected (Braun and Clarke, 2021).

Systematic data coding

From the qualitative data the codes were developed for each individual participant and then the common codes were integrated to form the beginning of the themes. Some units of analysis contained two codes a primary code and secondary code. The secondary codes were captured obtaining as much information as possible from the open-ended questions helping to formulate secondary themes. The initial codes were colour coded and then transcribed into a table and listed against frequency to form a free format code book (Kumar, 2018). The researcher had a bias towards visual learning, therefore the colour coding helped the researcher identify links between the codes, and develop themes via visualisation (Erlingsson and Brysiewicz, 2017). The initial codes identify a specific unit of descriptive data which could be a sentence, phrase, or paragraph, identifying codes in this way can lead to an unmanageable number of codes, so when analysing the data, the codes related to the research question were considered the primary codes (Braun and Clarke, 2006). Strauss and Corbin (1998) describe three levels of coding within their qualitative data analysis framework, ‘open’, ‘axial’ and ‘selective’, but they do not go on to identify themes as Braun and Clarke do. In common with Braun and Clarke (2006), they define and develop codes in their ‘open’ level, make connections between categories in ‘axial’ level and then identify the main category in the ‘selective’ level. For these data it was felt that the Braun and Clarke (2021) model was a better fit since thematic analysis was the end point. Guest, et al. (2012) suggest that thematic analysis works well for complex meanings in textual data. The analysis of the content grew over time because the initial national survey was mainly qualitative questions and included only a few open-ended questions to collect qualitative data. The first interviews in the longitudinal study with the students were shorter than the second interviews with the same participants after they qualified and were working in first post, so the second interviews produced more codes but were a development from the initial interviews and drew on the experience of the now qualified students. The focus groups and in-depth interviews also provided large quantities of data.

Codes were not entered into a software system such as NVivo Qualitative Data Analysis Software (2018), because it was felt that this would have added to the time required for the analysis of data, although the system is able to generate schematics of the resulting themes easily. Since this was a one-off project with a sole researcher it was felt that manual coding was sufficient.

When coding the researcher needs to ask appropriate specific questions such as: when, where, and what is happening in the text (Braun and Clarke, 2021). Each section of the research - the national survey, longitudinal study, focus groups and interviews - were coded separately and the resulting themes led onto the next section of the research.

The initial codes were collated in a frequency table because this was an accurate method of organising the large amount of data. Frequency tables can be reviewed easily and then compared to data later in the study. Once the data collection was complete the final codes were compared with the codes identified throughout the data. The codes form the foundation blocks for the themes.

Generating initial themes from coded and collated data

After the data have been coding and collated the searching for themes can start. This phase identifies broader themes as opposed to the narrow initial codes. The colour coded codes were sorted into potential themes with their data extracts, some codes can be combined to form an overarching theme (Braun and Clarke, 2021). A thematic map was created from the initial codes and themes to help start developing a relationship between codes and themes. Different levels of themes, defining overarching, sub and miscellaneous themes were identified from the thematic map. At this stage, data were not discarded because they may become useful later after the themes are examined, redefined, combined, separated, and finalised. At the end of this phase rough themes have been developed but they need to be reviewed. Searching for themes is an indicative process where themes are revisited and refined several times during the analysis process.

Developing and reviewing themes

The original themes need to be refined and some of the candidate themes need to be discarded due to lack of data or if the data are too diverse (Braun and Clarke, 2021). The themes are not driven purely by frequency, it is not a quantitative analysis of the qualitative data, rather relevance and power need to be considered (Kiger and Varpio, 2020).

At this point some themes were combined due to their similar content and some were separated once their content was revisited, there should be a clear distinction between the coherent meaningful themes, and they should be related to the research question (Nowell et al., 2017). Patton (1990) describes this process succinctly as using the dual criteria of internal homogeneity and external heterogeneity (Patton, 1990; Braun and Clarke, 2021).

Refining, defining and naming themes

Themes were created using the language of the participants and the themes were substantiated by verbatim transcripts. Themes were identified before the focus group and in-depth interviews in the final phase and the open questions used for these were created from the three resulting main themes. In this phase the essence of each theme was identified (Dawadi, 2021). Complex and diverse themes can be included in the analysis (Braun and Clarke, 2021). Themes were developed further, and themes and sub-themes were identified and named.

Writing the report

The reports are written up in this dissertation, the cross-sectional survey in chapter four, the longitudinal study in chapters seven and eight, and the expert opinions in chapter ten.

3. 7 Cross-sectional study

Cross-sectional study designs are useful for obtaining an overall view of a population at a point in time (Kumar, 2018). Cross-sectional studies are popular and are usually a way of obtaining data from a large population quickly, easily, and cheaply using survey methodology (Sedgwick, 2014). Change is not measured in cross-sectional surveys because as they only involve one contact (Kumar, 2018). The advantages of survey approach are that quantitative and qualitative data can be gathered. Quantitative usually by completing a questionnaire and qualitative data simultaneously by free text comments, these offer wide and inclusive coverage (Denscombe, 2017). Cross-sectional studies are limited because these are self-reporting, lack depth and detail and causal conclusions cannot be drawn from them (Denscombe, 2017; Spector, 2019).

Questionnaires give respondents anonymity but are notorious for their low response rate and can be frustrating to participants due to lack of opportunity to clarify issues (Kumar, 2018). Denscombe (2017) point out that internet research has bias since it relies on visitors to websites and my not constitute a representative sample, this survey was advertised by the Society of Radiographers (SoR) online and in the professional journal, with the survey being available using a SoR link.

The survey was an existing survey which had been validated by peer reviewed publication and permission was sought and granted from the author. The cross-section survey was initially setup on online surveys (formally BOS) and was piloted with peers to check that it was error free and easy to use. A letter to introduce the survey was included to welcome participants to help elevate non-contact bias (Denscombe, 2017).

A cross-sectional survey was chosen as the first method of data collection in this study to gather information to give an overall view of the ability of radiographers to optimise dose and to formulate questions for the in-depth interviews. The participants were UK radiographers who were self-selecting. The link took the radiographers to the participant information sheet, after reading the information they could consent on the survey by ticking the consent box, before they could continue to the online survey.

Free text comments were allowed so the radiographers could voice their opinion and provide qualitative data. The response rate was low with the online survey so hard copy surveys were sent out to CT superintendents to distribute as purposeful sampling, leading to a greater response.

The results were analysed by descriptive statistics, comparison of means and thematic analysis using Braun and Clarke's framework (Braun and Clarke, 2021).

3. 8 Systematic reviews

Systematic reviews are characterised by clear methodology, including transparency, reliability and replicability and relevant inclusion criteria to give scientific quality (Moher et al., 2015; Gregory and Denniss, 2018; Belur et al., 2021). Systematic reviews are used in this research study to gain comprehensive information with limited bias with the prospect of gaining transferrable information from imaging and non-imaging clinical environments (Uttley et al., 2020).

Systematic reviews were developed over 30 years ago to produce more informative and reliable literature reviews, giving a rigorous approach to the review of literature (Mulrow et al., 1988; Greenhalgh et al., 2018). In the hierarchy of evidence systemic reviews are viewed as a robust scientific review of secondary current literature and therefore placed above narrative reviews, Greenhalgh et al. (2018) argues that systematic reviews should be considered complementary to narrative reviews and that systematic reviews only address narrow focused questions (Horsley, 2019). Diverse literature from several methods and perspectives are hard to synthesise into a concise summary (Horsley, 2019). Reporting guidelines for systematic review have been developed by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), whose tools allow for the preparation and reporting of a systematic review (Moher et al., 2015; PRISMA, 2021). The PRISMA checklists were originally developed for reviews evaluating the effects of interventions but can be used for evaluating other systematic reviews, the add rigour and consistency to the systematic reviews (Page et al., 2021; PRISMA 2021). The PRISMA guidelines have been updated recently and now include more checklists to increase the transparency of the systematic review process (Page et al., 2021). One of the changes to the PRISMA tool is to include the number of reviewers screening the records and whether they worked independently because reviewing can be subjective leading to variability of inter reader reliability, robust inclusion criteria help to mitigate variability (Belur et al., 2021; Page et al., 2021). This research project is being undertaken by a sole PhD researcher, so all the records were screened by one reviewer.

The Critical Appraisal Skills Programme (CASP) tool adds quality to the synthesis of evidence by assessing each article by answering the questions asked in the checklist, there is a specific tool for qualitative research (CASP-UK, 2021). Long et al. (2020) explain that CASP checklists are user friendly for qualitative research appraisal and are endorsed by Cochrane and the World Health Organisation to bring quality to research. They measure procedural aspects and inclusion of relevant details, but they may not help with the consistency of reviewers (Dixon-Woods, 2007). Williams et al. (2020) feels that CASP tools and similar checklists, such as Joanna Briggs Institute Qualitative Assessment and Assessment instrument (JBI QARI) include broad appraisal of reflexivity, transparency and dependability but not the qualitative methodology approaches or methods of collecting data and may need modification. If CASP tools are applied appropriately they are valued for adding structure and facilitate reviewing the articles for quality (Long et al., 2020). Appropriate CASP tools were used for the systematic reviews in this study.

To conduct an effective systematic review a focused question is required, which will be answered by the review, if a wider question is required then a narrative review should be undertaken (Gregory and Denniss, 2018). The most commonly used research question framework in systematic reviews is Patient Intervention Comparison Outcome (PICO), which was developed for quantitative reviews, but it does not capture all the elements of qualitative reviews. It can lead to ambiguous questions that do not address the problem in articulate and interrogative manner (Rehman, 2021). Several researchers have redefined the PICO components to fit the mode of research being used. An alternative to this is to use another research question framework such as Sample, Phenomena, Design, Evaluation, Research (SPIDER) or Population Exposure Outcome (PEO), with PEO being used for qualitative research and SPIDER being used for mixed method qualitative studies where small sample sizes are explored in-depth

(Korstjens and Moser, 2017; Capili, 2020; Rehman, 2021). SPIDER framework can help to formulate an open and broad research questions (Korstjens and Moser, 2017). Grindlay and Karantana (2018) point out that PICO and PEO are not just search concepts they should think carefully about how to define their search question and thus search strategy. PEO requires an outcome but PICO users can modify PICO so it does not require an outcome because they can be difficult to define (Grindlay and Karantana, 2018). The PEO research question framework was selected to be used in this study for the systematic review. The SPIDER framework was used in this study to formulate the overall research question.

3.9 Longitudinal study

Longitudinal studies are designed to measure phenomena that change over time but present many challenges especially if they are mixed methods, due to their complex nature (Plano Clark et al., 2015). Longitudinal studies can increase confidence in the inferences about causality when compared to studies with one observation (Wang et al., 2017). Longitudinal studies require clear research design and careful thought about the analytical approaches (Diefendorff et al., 2021).

Wang et al. (2017) explain that the length of time between data collection should be a meaningful time, in this study data were collected from radiographers pre- and post-registration in a timeframe of two years. Pre-registration data were collected just prior to qualification and post-registration data had to be collected after the participants had qualified and undertaken CT examinations as part of their post-registration role.

Longitudinal qualitative methodology has become increasing popular because it can identify the causes, experiences, and consequences of change (Calman et al., 2013). Longitudinal qualitative research is suited to capturing transitions in a person's life and is used in this study to capture the changing experiences as radiographers transition from pre-to post-registration (Calman et al., 2013).

Fully longitudinal mixed method (MM) studies collect data qualitative and quantitative data at all time points. Prospective and retrospective models collect quantitative data at all time points with qualitative data collected once, at the first time point for prospective models and at the last timepoints for retrospective models (Van Ness et al., 2011). Fully longitudinal MM studies are costly and complicated and could introduce bias in the qualitative data in the related measure design (Van Ness et al., 2011). In longitudinal MM themes can be developed across time and results can be integrated giving a time dimension to the analysis (Zhang and Liu, 2019).

Mixing qualitative and quantitative methods in longitudinal studies can enhance the study and add to knowledge, and provide insights in social science (Holland, 2011). Analysis is complex with multidimensional data; cross-sectional analysis can occur at each time point to capture differences in participants and longitudinally to capture a participants' contribution. Themes can show what is happening at each time point through giving a more descriptive narrative (Calman et al., 2013).

3.10 Saturation

Saturation of the qualitative data was considered in the conceptual framework underpinning this study. Saturation can add depth, and quality and rigour to a study (Varpio et al., 2017; Stenfors et al., 2020). Qualitative research can involve a small number of participants, providing in-depth interviews giving insight into the phenomena being researched (Stenfors et al., 2020). Hennink et al. (2017) explain that the small number of studies can provide comprehensive data but to provide deep uniform understanding of the issues more data will be required.

Qualitative research differs from empirical data and although people have tried to calculate the number of people to interview to obtain saturation there are no confidence interviews or other metrics to report from qualitative data (Guest et al., 2020). There is no consensus of how to objectively establish saturation in qualitative research, although in thematic analysis it is believed that saturation can be achieved when further observations and analysis show no new themes (Lowe et al., 2019). Hennink et al. (2017) advocate that saturation has multiple meanings which remain unclear in practice. Saturation is dependent on the methodology, and Malterud et al. (2016) feel that information power would be a more valid concept meaning that the more relevant information available in the sample the lower the number of participants need.

Saturation was achieved in this study by triangulation via focus groups and in-depth interviews of experts in the field as well as the use of mixed methods methodology. Varpio et al. (2017) point out that data acquired for saturation has the danger of revealing new themes, to mitigate these semi-structured questions aligned by using the themes developed in the previous stages of the study.   Studies often declare saturation but do not explain how it was achieved (Hennink et al., 2017).

3.11 Limitations

There was a poor response rate to the cross-sectional survey online and hardcopy questionnaires were sent to participants to increase the response rate.

There were a small number of participants in the longitudinal study and over a third did not get to work in CT scanning.

The COVID-19 pandemic influenced recruitment for the triangulation of qualitative data, by expert opinions via the focus group and face-to-face interviews.

The amount of Mixed Method research a sole researcher can facilitate is limited.

3.12 Summary

This Mixed Method study was complex, and consisted of three linked convergent parallel methods, integrating, and connecting quantitative and qualitative data proceeded by three linked reviews.

The Mixed Method methodology consisted of:

- An exploration of radiographers' knowledge of exposure parameters and view on education using a cross-sectional methodology

- An exploration pre- and post-registration radiographers' knowledge and experience of dose optimisation within CT scanning, emotional intelligence, and the radiographers' educational, social and clinical experience using a longitudinal study and

- Qualitative methods to explore radiographers' (focus group) and medical physics experts and radiologists (semi-structured interviews)

The relationships between social and educational factors in the clinical environment are complex and therefore this study required complex methodology to explore in depth, with consideration to triangulation, the training of UK CT radiographers

Chapter 4- Cross-sectional survey

4.1 Introduction

The number of CT scans in UK and worldwide is increasing due to technological advancements and the availability of CT scanners with an expected 100% increase in England and Wales from 2020 to 2022 (Dixon, 2020; NHS England 2020; Tsapaki, 2020). Dose reduction in CT is important because even at low doses there is a small excess risk of cancer and therefore dose optimisation is major principle of radiation protection ensuring that the effective dose to the patient is kept as low as reasonably achievable (ALARA) (Serum, 2015; Hauptmann et al., 2020). Riley et al. (2014) advocate that dose optimisation is best realised by an inter-professional team consisting of radiographers, radiologists, and medical physics experts; this is a COMARE recommendation and was recently advocated by the American Association of Physicists in Medicine image wisely campaign (Chell,2016; Mahesh, 2018; Tsapaki, 2020; Association of Physicists in Medicine, 2022).

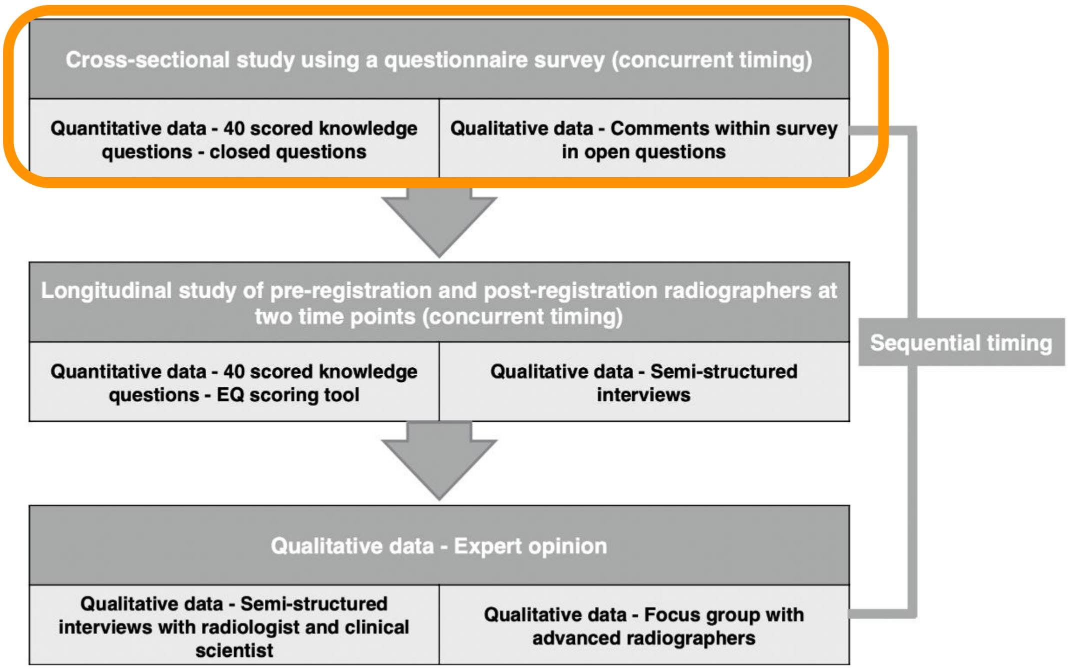

Figure 4.1 - *Schematic diagram of the research design- part 1 cross-sectional study*

The objective of the full study is to explore academic and social factors' effect on optimisation of patient dose during CT scanning. This cross-sectional study, highlighted in Figure 4.1 above, is the first part of the study and explores dose optimisation by UK Radiographers using a modified version of an existing published questionnaire (Foley et al., 2013). Demographic, quantitative, and qualitative data were obtained.

4.2 Background

The current demand for CT scans in the UK is estimated to be increasing between 10% and 29% per annum and although it is considered a mature modality, applications are being developed continuously contributing to the increased demand (RCR, IPEM and the SCOR., 2015, Barclay, 2016, Royal College of Radiologists, 2016, NHS England 2020). There has been concurrent growth in the use of CT due to the emergence of hybrid imaging in the nuclear medicine environment, increased applications, and greater availability of scanners (Bellolio et al.,2018, NHS England 2020). PET- CT scanning is likely to increase 10% per annum, SPECT-CT is also increasing, Griffiths et al. (2014) indicate that there is a great variation in optimal use of CT in hybrid imaging (NHS England 2020). There has been an overall reduction in patient dose per scan over the last ten years but there is a large variability in effective dose between sites, machines, and countries (Stocker et al., 2018; Smith-Bindman et al., 2019).

The effective dose to the patient depends on CT scanner design and how CT parameters are selected (Trattner et al., 2018; De Mattia et al.,2020). Radiographers, radiologists, physicists, and application specialists therefore have a key role in the reduction of dose (Elliott, 2014). Radiographers have control over how the scanner is used through selection of appropriate exposure parameters and dose optimisation. A recent survey found that the influence of some parameters is not well understood by radiographers and radiologists, and that there is a need for on-going education in dose optimisation (Foley et al., 2013); Strauss et al. (2010) support this view and believe that a medical physicist should be available to ensure that the technical aspects of the CT are properly understood. At inspection, the Care Quality Commission (CQC) highlight the importance of support from medical physics experts in optimising patient doses and in comparing local doses with the national diagnostic reference levels for CT scans (Care Quality Commission, 2020).

Radiologists need to feel confident that the images produced are of diagnostic quality; a balance is required between radiation dose and image quality. Operators tend to use increased radiation exposures to create X-ray images with low noise levels, but CT images are created from attenuation maps so there is no direct indication of patient overexposure. The Dose Length Product (DLP) and CT Dose Index (CTDI) are a guide to exposure. Post-acquisition image reconstruction can reduce the level of image noise while maintaining low dose (Sulieman et al., 2021). Zarb et al. (2011) concluded that image quality is detrimentally affected by dose reduction thus effective dose optimisation limits need to be set (Patel et al., 2019). Brenner and Hall (2007) propose that epidemiological studies of atomic-bomb survivors and radiation workers in the nuclear industry concur. When considered with Pearce et al. (2012) retrospective cohort study of radiation exposure from CT scans in childhood, evidence is provided to support the notion that there is an increased risk of cancer from organ doses corresponding to CT doses used in medical imaging. When epidemiological studies are considered with existing knowledge; the evidence that ionising radiation, at CT dose levels, increases the risk of cancer is reinforced (Harbron, 2016; Hauptmann et al., 2020). The CQC indicates effective dose from CT exposures is at CQC,2013, 2021).

Children are a particular concern since their organs are more radiosensitive than adults and the effective dose from a CT scan is higher than in adults (Wall et al., 2011; Berrington De Gonzalez et al., 2021). The lifetime risk of cancer from CT scanning is a function of age at exposure, and the patient gender. The risk from a Chest/Abdomen/Pelvis CT scan is 1500 per million for a female and 960 per million for a male when calculated for a 0–9-year-old patient. The risk is reduced to 2.1 per million in females and 3.3 per million in males for patients over 90-year-old (Zarb et al., 2011, Wall et al., 2011).

4.3 Method

This was a cross-sectional study using a questionnaire to collect large amounts of data quickly and easily. The availability of online tools for questionnaires means that participants from a wide geographical area could be recruited simply. Bristol Online Survey (BOS), (now Online surveys), was the electronic survey tool used for the survey due to the fact it was available at the university. BOS cannot interrogate geographical area by IP addresses so the exact geographical area of the participants was unknown and on reflection this should have been added as an extra question. The questionnaire contained sections for comments where appropriate and ended with a space for additional comments, so respondents could enter free text providing qualitative data. The questionnaire used for this study was adapted from '*A questionnaire survey reviewing radiologists' and clinical specialist radiographers' knowledge of CT exposure parameters'* (Foley et al., 2013). Permission was granted from the authors of the original study and being an established tool, comparison between the findings of the previous study and this new study could be undertaken. The questionnaire responses were anonymous with no identifiable information. Section 1 of the questionnaire required demographic information and the participants qualifications. Section 2 tested the radiographer's knowledge of CT protocols and parameters and their effect on dose optimisation and image quality; these questions were quantitative questions requiring a 'true' or 'false' or 'yes' 'no' responses. The questionnaire adaptations were minimal: the addition of extra categories of experience, from zero to > 26 years as opposed from 5 years to greater than 25 years in the original questionnaire; participants were asked for their qualifications, since this links to the other phases of this PhD study. The last question regarding diagnostic reference levels (DRLs) was altered to reflect DRLs available in the UK. Each country in Europe has its own version of National DRLs and some countries do not categorise in the same way, so four body areas have been selected Head (stroke), Chest (Lung cancer), Abdomen (liver metastases), Chest-abdomen-pelvis (cancer).

Confidence levels in altering CT parameters were measured via a five-point Likert scale (Bell, 2014). The radiographers' knowledge of protocols and parameters and their effect on dose optimisation and image quality was obtained providing quantitative and qualitative data via open and closed questions. There were 40 knowledge questions, which were scored and compared to the previous study.

The questionnaire was piloted with experienced CT lecturing colleagues since the questionnaire had been adapted from the original. Colleagues checked it had been transferred correctly on to BOS and that participants would find it logical and easy to use. Participants in the pilot were asked not to participate in the main study.

The Society of Radiographers aided recruitment of a convenience sample by giving permission to publicise the survey via their website and professional journal. Participants were self-selected and a web-link guided recruits to the participant information sheet. Participants were radiographers working in CT scanning in the UK. All participants were over 18 years old; there was no upper age limit. It was anticipated that participants should take approximately 20 minutes to complete the electronic survey. The survey was opened online for a period of 5 months. The response rate was low so additionally, purposive sampling occurred via hard copy distribution of questionnaires via CT superintendents. The application for ethical approval was accepted and approved by Health and Human Science Ethics Committee (aHSK/PG/UH/00389) and an amendment was granted for the hard copy questionnaires.

The data collected were anonymous and informed consent was implied by submission, participants were free to withdraw at any time up to the submission of the survey (Hadley and Watson, 2016). After the questionnaire was submitted participants were not able to withdraw consent. Hard copy participant information sheets and consent forms were sent to radiographers wishing to participate in the survey via the hard copy forms. The consent forms were returned separately from the questionnaires. No coercion of any type was used in this study.

4.4 Results and discussion

In this chapter the quantitative and qualitative findings of the cross-sectional survey will be presented together with analysis of the results. The quantitative results will be compared to previously published results. Thematic analysis was used to analyse qualitative results.

Participants for the cross-sectional survey were self-selecting UK radiographers and a web-link guided recruits to the study information sheet, the data statistics available from the Bristol Online Survey (BOS) showed that 157 people looked at the survey but only 19 people completed it giving a 12% completion rate. After an ethics amendment purposeful sampling occurred via hard copy distribution of 82 questionnaires which resulted in a 34% response rate of 28 completed surveys, giving a total of 47 participants. Inclusion criteria were radiographers in the UK working in CT scanning.

Survey results were analysed via descriptive statistics and thematic analysis. Quantitative data collected in the questions about protocols and parameters were given a score of 1 for a correct answer and a score of zero for incorrect answers. Mean scores of the group were compared with the groups in the previous published study, which were analysed using the same method. Open-ended questions providing qualitative data were coded and trends emerged which identified the main themes.

4.4.1 Quantitative data

This cross-sectional survey had a response of 47 completed questionnaires from UK radiographers, their characteristics are shown in table 4.1. The UK radiographer cohort had a median of six to nine years CT experience. The regional location of the responders to the paper-based survey is shown in figure 4.2.

Table 4.1 - Participant characteristics table

UK radiographers - Participant characteristics (number of responses)	
Number of years qualified	
Under 6 years	21
Between 6 and 12 years	11
Between 12 and 18 years	7
Over 18 years	8
Qualifications	
BSc	31
DCR(R)	14
Unspecified	2
Post Graduate qualification	20
Post Graduate Qualifications [a]	
Post graduate certificate in CT scanning	12
MSc	2
PhD	1
CT image interpretation	8
Post graduate certificate in other modalities	5
Unspecified	2

[a] Note: Multiple responses were allowed for this question

The regional location of the responders to the paper-based survey

The 28 responders to the paper-based survey were from six regions. The regions of the online responders could not be identified since BOS does not give access to the responders' IP addresses. The map below shows the number of responders in each region.

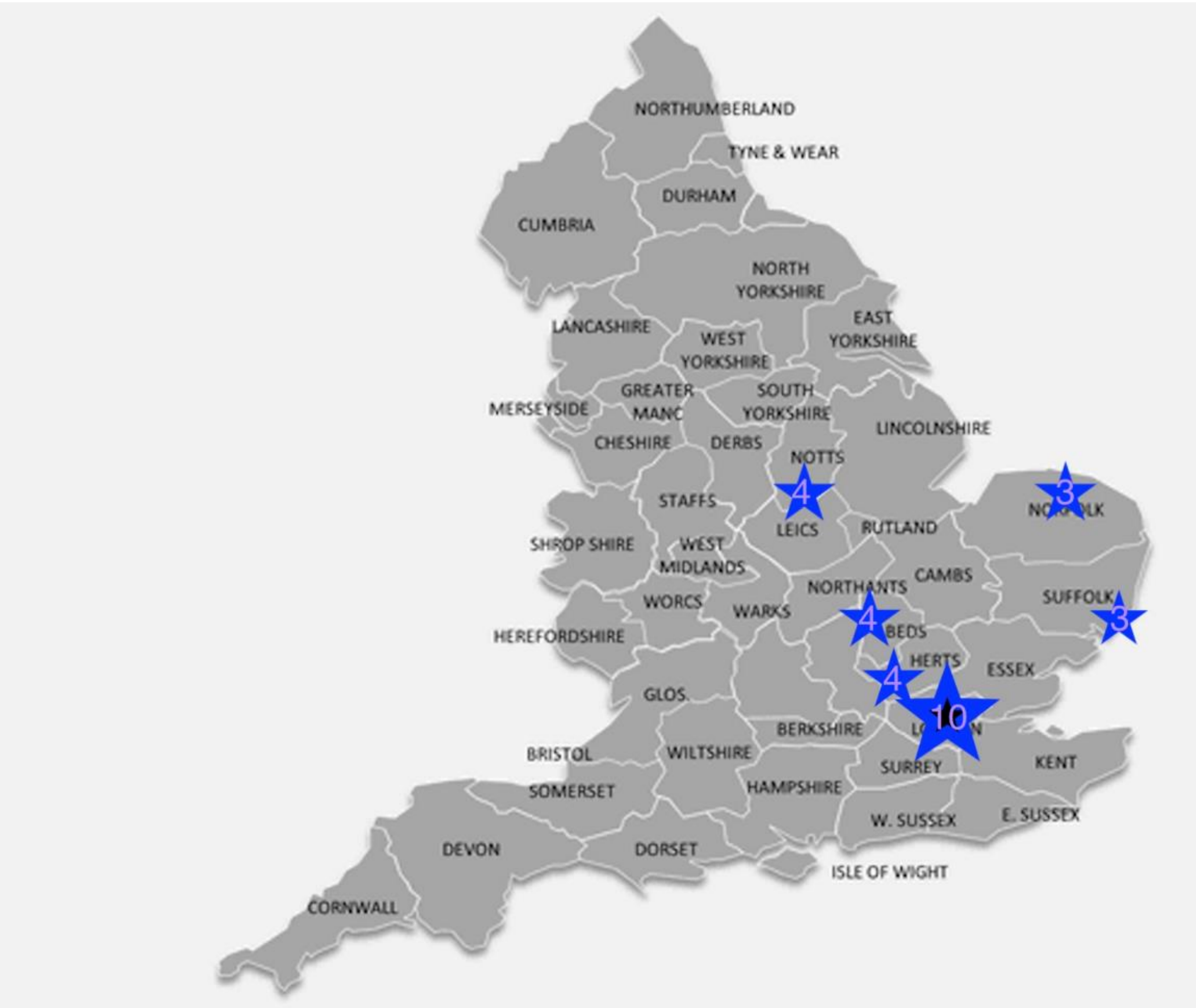

Figure 4.2 - The regional location of the responders to the paper-based survey

Protocol and parameter questions

UK radiographers fared better in the scoring of the 40 protocol and parameter questions when compared to previously published data from Radiologist and Irish radiographer cohorts.

The comparison between the published scores and the cross-sectional study scores can be seen in Table 4.2.

Table 4.2 - *Comparison scores between published paper (Foley et al., 2013) and UK radiographers*

Profession	*n*	Mean	SD	Min	Max
ABR Radiologist	14	27.8	4.2	20	34
Irish CSR	21	28.1	4.3	18	36
Published total	35	28.0	4.2	18	36
UK radiographers	47	29	3.7	23	36

Foley et al. (2013) compared radiologists with Irish Clinical Specialist Radiographers (CSRs). This study contributed to the further work encouraged by Foley et al. (2013), assessing the understanding amongst larger groups of radiographers, this study assessed the understanding of UK radiographers. The comparisons are set out using the sub-headings used by Foley et al. (2013) in the results and discussion sections of their published article.

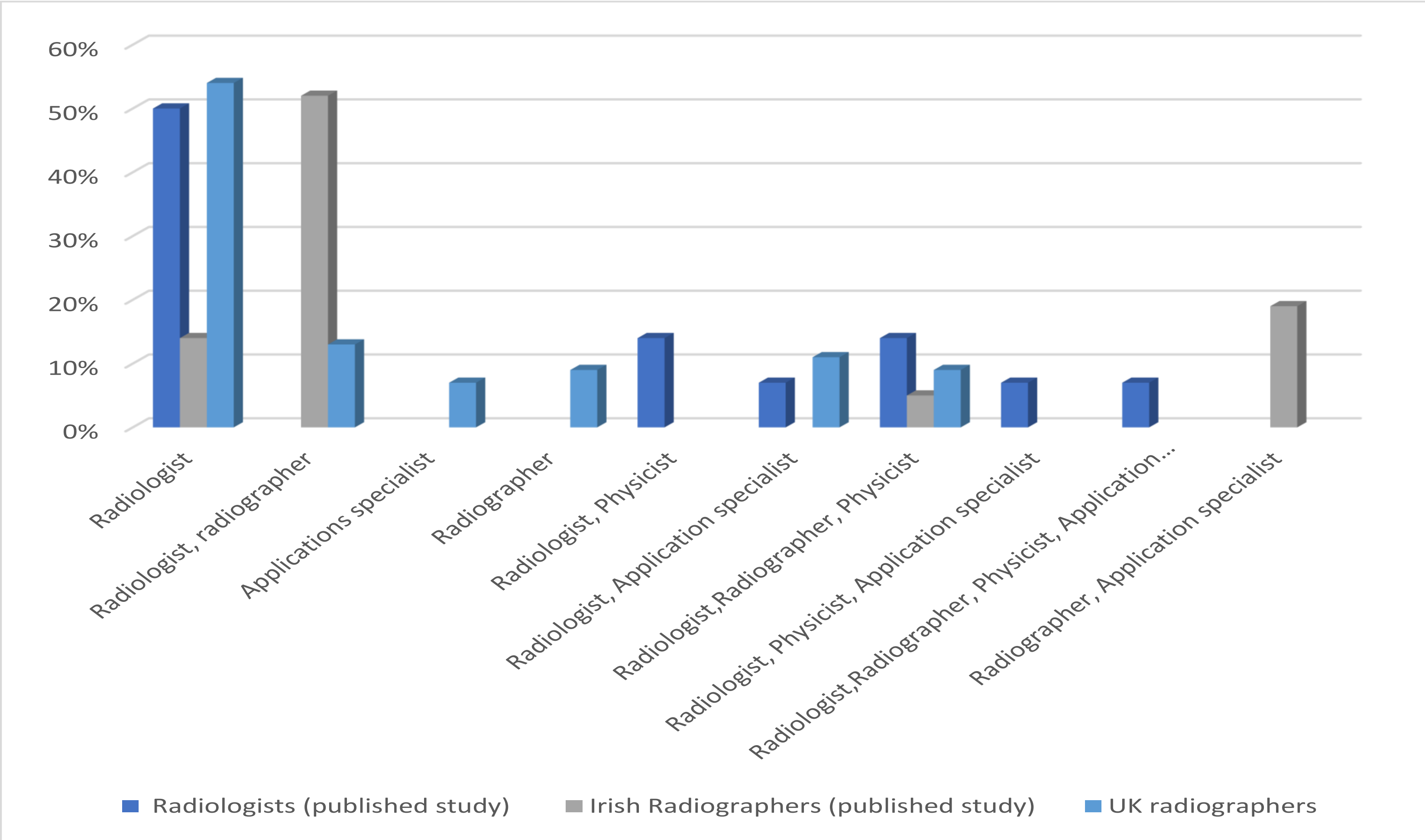

Figure 4.3 - *Who decides on CT scan protocols in your department*

CT Protocols

Only 9% of UK radiographers reported that multi-disciplinary team working was occurring in their departments with 54% of respondents indicating that radiologists alone set the protocol. This correlated highly with the previously published study by Foley et al. (2013), indicating that 14% of radiologists reported collaborative working and 5% of Irish Clinical Specialist Radiographers (CSRs), thus demonstrating that full multi-disciplinary team working was not occurring in these departments at that time. Half of the radiologists surveyed from the Foley et al.(2013) study reported that they set protocols alone (without the help of the multi-disciplinary team) compared to 54% of radiologists in this study, however only 14% of Irish CSRs reported that radiologists alone set the protocols. The discrepancy between the CSRs and the other two groups can be explained by the fact that CSRs are radiographers who have operational responsibility and as part of their role they normally work with radiologists to optimise protocols.

Figure 4.3 compares the Foley et al. (2013) study with the UK radiographer's study showing who decides on protocols within their department. In the departments staffed by the respondents, it is recommended that for new protocols or existing protocols being designed or modified an inter-professional group consisting of lead radiologist, lead CT radiographer and medical physicist should decide on the protocols collaboratively. With only 14%, 5% and 9% of radiologists, CSRs and UK radiographers' departments respectively complying with the recommendations.

Most UK radiographers altered the CT parameters for anatomical area (33/47, 70%) and study indication (32/47, 68%). A greater percentage of radiologists (85%) altered the CT parameters for anatomical area (33/47, 70%) and study indication. Foley et al. (2013) were worried about the significant percentage of CSRs who did not alter the CT parameters for anatomical area (57%) and study indication (48%).

Recent changes in CT protocols

34% (16/47) UK radiographers had not seen a change in protocol in the last two years. The reasons for the other 66% changing their protocols were: 17% (8/31) due to installation of a new scanner: 2% (1/31) for new software: 23% (11/31) to reduce/optimise dose, with some to conform to Royal College of Radiologists guidelines: 4% (2/31) to comply with research protocols and 15% (7/31) for evolving protocols, such as thinner slices, renal scanning: and staging, mostly driven by radiologists, two people did not give details.

Concerns about CT dose

More than a third (36%) of UK radiographers who responded had concerns about CT dose in their departments. This compares with 65% and 40% respectively for radiologists and CSRs in Foley et al. (2013). UK radiographers did not comment on their concerns in the free text section.

ATCM operation

The question with the most incorrect answers was the question on automated tube current modulation (ATCM): 92% of respondents answered the section about the fact that ATCM can be influenced by centering correctly but only 57% correctly answered the section on the use of ATCM in the presence of metallic implants.

Table 4.3 - Number and percentage of each group in agreement with statements below

Statement	Radiologists*		CSRs*		UK Radiographers	
	n	%	*n*	%	*n*	%
ATCM is affected by centering of patients in the gantry	12	85	19	92	43	91
ATCM should not be used in the presence of metallic implants	11	77	11	52	19	40
The non-contrast phase of an abdomen scan requires the same image quality/noise	1	8	6	29	4	9

* *From Foley et al study. Participants in the study were radiologists, attending American Board of Radiology exams, and Irish CT Clinical Specialist Radiographers (CSRs).*

Dose variations of up to 41% are associated with the incorrect use of the ATCM (Matsubara et al.,2009). The majority of the UK radiographers (91%) were aware that ATCM can be influenced by how the patient is centered within the gantry. This matched Foley et al.(2013)'s findings of 85% and 92% for radiologists and CSRs respectively.

When compared to the radiologists and CSRs, fewer of the UK radiographers (40%) believe that ATCM should not be used in the presence of metallic implants. With over half (52%) of CSRs and over three quarters of radiologists (77%) believing that the ATCM should not be used in the presence of metallic implants. Studies have shown that a net reduction in tube current occurs with ATCM, even though the tube current may increase over the region of the implant, when compared to a fixed tube current. (Rizzo et al., 2005). Some modern software can disregard the tube current adjustment for the metallic area when the scan is initially setup with the scanogram, therefore reducing the net tube current. (Dalal et al., 2005).

A similar percentage of UK radiographers (9%) to the radiologists (8%) believed incorrectly that the non-contrast phase of an abdomen requires the same image quality/noise setting as the contrast phase. Whereas almost a third of CSRs (29%) believed incorrectly that the non-contrast phase of an abdomen requires the same image quality/noise setting as the contrast phase.

Peak kilovoltage (kVp)

Foley et al (2013) asked participants the effect of reducing the kVp from 120 to 100 kVp for angiographic CT produces. Most CT systems operate at 120 kVp, reducing the kVp can reduce the radiation dose but increase image noise. A lower kVp can increase vessel attenuation in angiographic studies. Foley et al (2013) reported that; "almost 40% of CSRs did not associate reductions in kVp with increased image noise" (p641). When the UK radiographers answered the same question almost a third (34/47, 28%) did not associate reductions in kVp with increased image noise, faring better than the CSRs but worse than the radiologists at 21%.

Foley et al. (2013) found that 52% of CSRs and 74% of radiologists agreed that lower tube voltages result in increased vessel enhancement during angiographic examinations. The UK radiographers score was in-between the CSRs and radiologists with 29/47, 62% agreeing that lower tube voltages result in increased vessel enhancement.

Tube Current (mA)

Concurring with Foley et al. (2013)'s findings, the majority (75%, 35/47) of the UK radiographers agreed that there was a linear relationship between tube current and radiation dose. Foley et al. (2013) state that 71% radiologists and 80% CSRs agreed that there was a linear relationship with dose. Foley et al. (2013) explained that there was confusion over the relationship between tube current and noise, with over half (54% radiologists, 55% CSRs) of both cohorts believing that there was a linear relationship instead of tube current being inversely proportional to noise. Foley et al. (2013) feared that an incomplete understanding of the relationship between tube current and noise would lead to challenges achieving dose optimisation. At 53%, the UK radiographers had a similar level of misunderstanding.

Image noise

93% of radiologists, 67% CSR and 72% UK radiographers (34/47) agreed that kVp selection influences image noise in CT
50% of radiologists , 62% CSR and 53% UK radiographers (25/47) agreed that image noise is influenced by window width setting
71% radiologists, 86% CSR and 72% UK radiographers (34/47) agreed that the reconstruction algorithm influenced image noise.

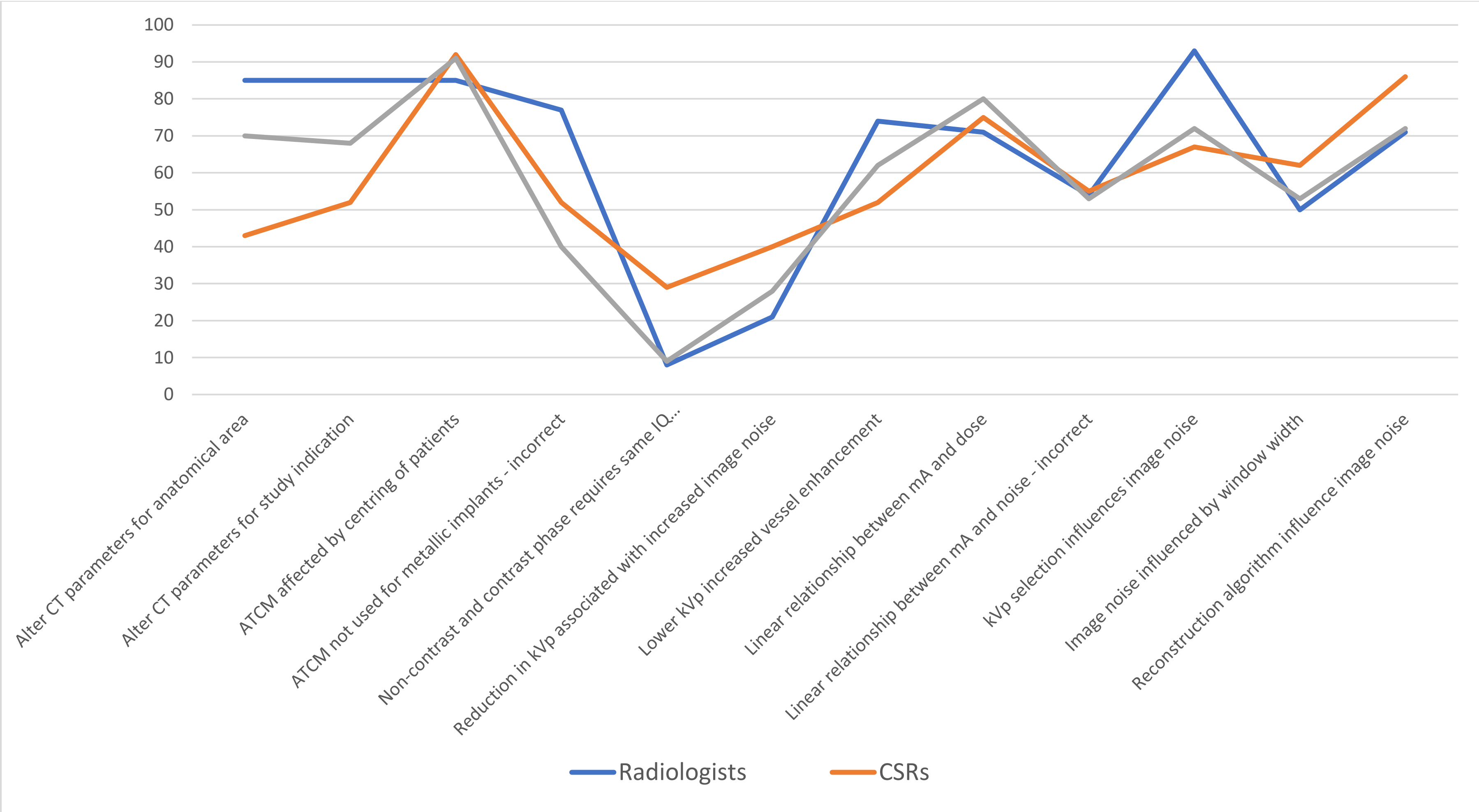

Figure 4.4 - *Answers to parameter questions, a comparison of UK radiographers, Radiologists and CSRs*

Summary

Figure 4.4 shows a comparison between radiologists, CSRs and UK radiographers. For most of the questions the score for the UK radiographers was between the radiologists and the CSRs.

UK radiographers fared better than Radiologists or CSRs in two questions:

- In one question the majority of UK radiographers (80%) believed that there was a linear relationship between tube current and radiation dose, 71% of radiologists and 75% CSRs believed that there was a linear relationship.
- In another question 60% of UK radiographers knew that ATCM should be used in the presence of metallic implants whereas only 48% of CSRs and 23% of radiologists knew that ATCM should be used.

Limitations

The Foley et al. (2013) study and this study had similar limitations with small numbers, radiologists 14, CSRs 21 and UK radiographers 47, due to the low response rate. Foley et al. (2013) included radiologists and CSRs which are experts in their fields. The UK study included any CT radiographer who wished to participate, Foley et al. (2013) only included participants that had more than five years' experience in CT whereas in the UK study the majority of respondents 21/47 (45%) had less than 6 years' experience in CT scanning. In both studies it could be argued that selection bias occurred, since radiographers feeling confident to answer the questions were most likely to answer the questionnaire.

Awareness of Diagnostic Reference Levels (DRLs)

At the present time, it was felt that awareness of DRLs was not required for this part of the study and analysis of these questions will be undertaken as future work.

Analysing the quantitative data from the survey helped to develop a method which could be used with the vast amount of data produced from the transcripts of the recording in the other phases of this study.

4.4.2 Qualitative data

Initial codes were generated from the free text responses from the survey and themes were then identified from the comments. The quantitative data were obtained at the same time as the qualitative data, both approaches in parallel. In the survey the quantitative tool was dominant, the qualitative data were collected via open ended questions (Brannen, 2005; Hammarberg et al., 2016). The qualitative data did not demonstrate complimentary or contradictory findings when married with the quantitative results. The results obtained from the free text data were used to refine and formulate questions for the interviews in the longitudinal study, the next phase in this study.

Analysis of qualitative data was prepared in a systematic and rigorous manner so it could be explored indicatively using content analysis to produce codes and themes (Pope et al., 2000). Thematic analysis following the Braun and Clarke (2021) qualitative data analysis framework was used to produce these findings.

Education

Although 40% of UK radiographers responding to the survey had Postgraduate qualifications, 98% felt that further education within optimisation of CT parameters would be beneficial. Thematic analysis identified education as the main theme with five sub-themes. The sub-themes were standardised training at undergraduate level: postgraduate training; on-the-job training; CT focused CPD; manufacturer's training. Some comments gave a positive view of the training method, while others reflected a negative view. Sub-categories are shown in the frequency table (table 4.4).

Table 4.4 - *Frequency table – Education*

Sub-category	Number*
Standardised training at undergraduate level	2
Training from manufacturers/applications training	5
Regular continuing CT focused updates, including study days	8
Further education to master's level/ postgraduate training	3

Sub-category	Number*
On the job training	2
Other	6

*Numbers are individual mentions.

Standardised training at undergraduate level

Standardised training at undergraduate level was a concern because participants felt that this would empower radiographers to manipulate exposure parameters to optimise dose.

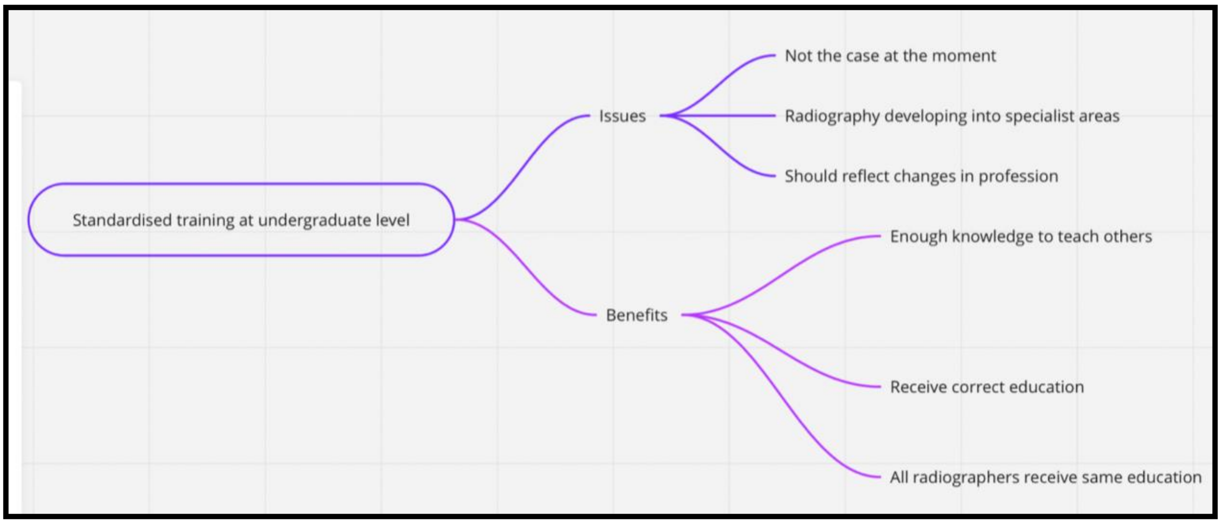

Figure 4.5 - *Mind map for standardised training at undergraduate level sub-theme*

Some UK radiographers' felt that specialist education for CT scanning could be addressed at undergraduate level:

"It seems the great majority of radiographers learn CT on-the-job rather than in an educational organisation………………… As radiography develops into specialist areas, I believe undergraduate programmes would reflect the changes in the profession."

Radiographers did not comment that undergraduate training would become out-of-date over time. Over half the participants (55%) had been qualified six years or over, starting their training nine years previously, the massive advances in technology could mean that only current undergraduate training would be up to date. It is not clear if the some of the respondents felt that the undergraduate programmes should be divided into separate programmes for modalities such as CT or MRI scanning. This demonstrates a frustration regarding comments on a questionnaire when compared to face-to-face interview since probing questions cannot be asked.

UK radiography courses are already accredited by the Healthcare and Professions Council (HCPC) and the Society of Radiographers (SoR); thus, courses already have uniform content. The growth and diversity of the profession with technical advances and advances in practice such as clinical reporting and cannulation by radiographers means that there may be a case for a four-year course. The course would cover all aspects or may require compulsory postgraduate courses for specialised modalities such as CT scanning. CT head scanning is a minimum entry requirement for the profession so departments feel that radiographers should receive CT training at undergraduate level (Health and Care Professions Council, 2013).

Training from manufacturers/applications training

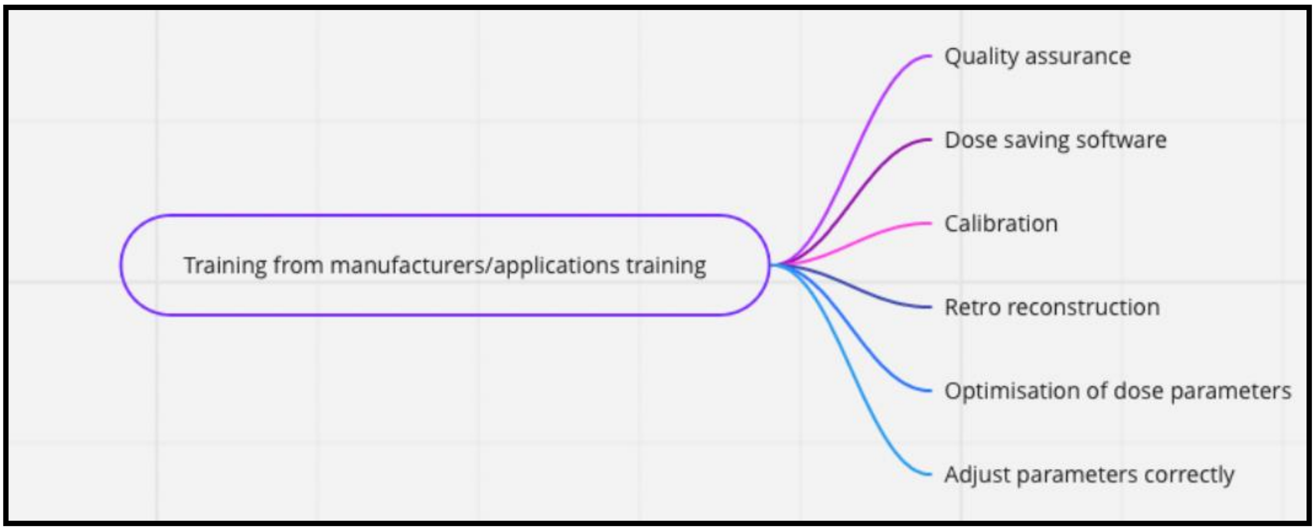

Figure 4.6 - *Mind map for training from manufacturers/ applications training sub-theme*

UK radiographers felt that they needed recent application updates or specific manufacturer's training to reduce /optimise dose by learning more about the technical

"I think further education in the new dose saving things (e.g., CAREDOSE) offered by companies would be beneficial"
"Training and education on how to adjust parameters correctly would be helpful

aspects of specific scanners. They were interested in calibration, quality assurance, retro reconstructions and dose saving software to obtain maximum performance from the CT scanner the are using:

Regular continuing CT focused updates, including study days

This sub-theme attracted the greatest number of comments.

Examples of comments included:

"Study days on how to optimise parameters to gain diagnostic images with reduced radiation dose"
"More education and awareness about CT scanning parameters. Training and CPD should be encouraged in the department."

Radiographers realised the limitations for the department to allow radiographers to go to courses outside the department and for the cost of the training. Most departments are now working twelve-hour shifts and have a limited budget to backfill staff who attend outside training. Study evenings or days in the department can be a cost-effective solution with a large majority of the staff being able to attend. Local speakers, such as other expert staff, regional medical physics experts and radiation protection advisors or local university staff can also be invited to contribute. Journal clubs or other forms of CPD can contribute to radiographer's knowledge and update staff. One person suggested a poster for the department which would be a constant reminder and reference point for staff.

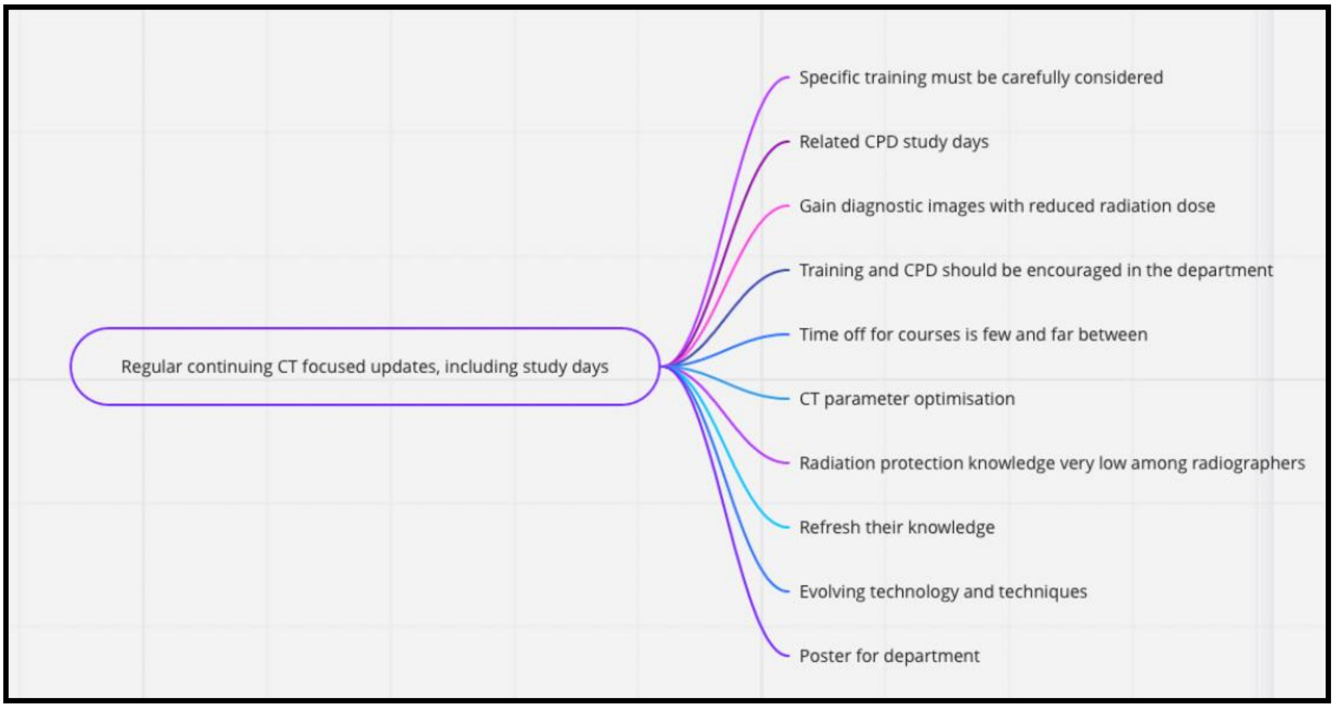

Figure 4.7 - *Mind map for regular continuing CT focused updates, including study days sub-theme*

Further education to master's level/ postgraduate training

Postgraduate courses are a solution for specialised relevant learning and normally include physics, applications, anatomy and physiology, legal aspects, protocols, techniques, and procedures with a dissertation if taken to master's level. Postgraduate courses empower radiographers with tools to critically evaluate evidence which means that they can appraise literature when new techniques are suggested and continue with a lifelong informed education. Postgraduate courses are expensive, normally taking between 18 months to five years and can only teach the knowledge available at that time so knowledge gained can go out-of-date. Radiographers undertaking postgraduate courses can form a network and this has real benefits to future-proof

“The lack of postgraduate CT training in my department is telling.”
“It is a long time since I did my Postgraduate Certificate and technology has advanced significantly in that time.”

their knowledge by communicating with likeminded peers.

Examples of comments included:

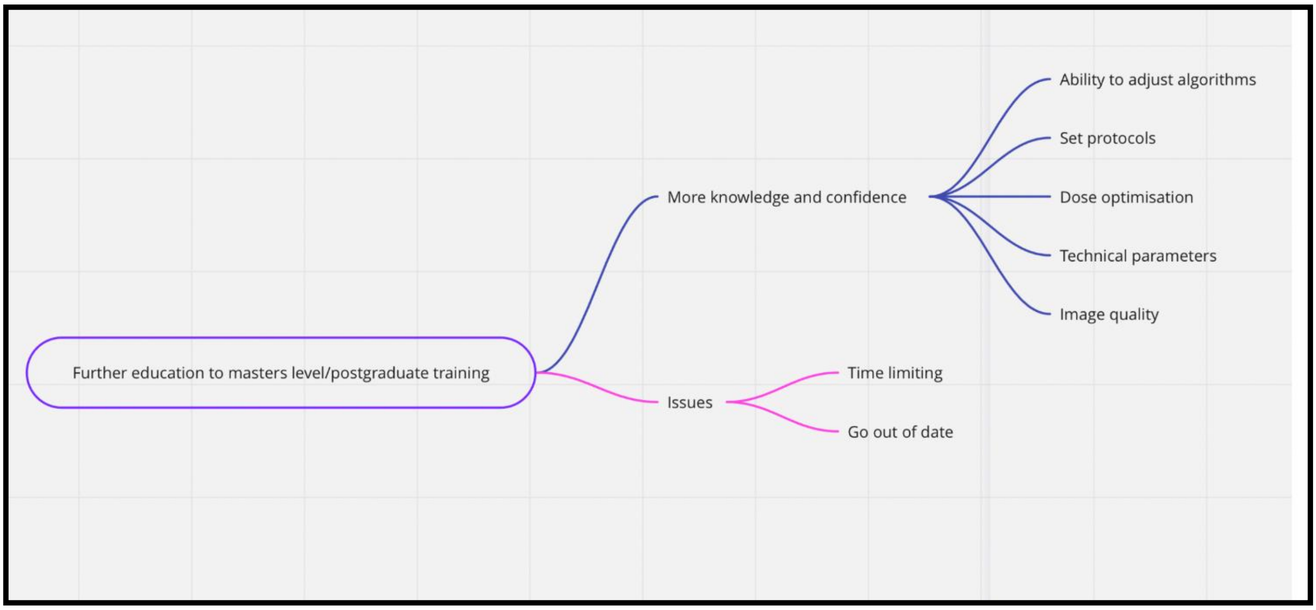

Figure 4.8 - *Mind map for further education to master’s level/ postgraduate training sub-theme*

On-the-job training

The comments about on-the-job training were negative. The feeling from the participants was that radiographers were learning from other radiographers on-the-job, and that the radiographers teaching did not have a sound knowledge of the subject:

“As CT is often learned "on the job" you tend to learn what the person teaching you knows - this person often does not have a full appreciation of the fundamentals of CT.”
“It seems the great majority of radiographers learn CT on the job rather than in an educational organisation. These radiographers are capable of performing the scans but some of them above 70% don’t know how technical parameters may affect dose and image quality.”

Additional comments

“R*egular updates would be of value - very easy to become a button pusher*.”
“*Understanding the radiation issues behind CT protocols is key to the CT radiographers role. Who else would do this vital job?*”
“This survey has highlighted areas I need to read up on.”

4.5 Conclusion

This cross-sectional survey allowed a generalised view of radiographers’ knowledge of exposure parameters and the education required to achieve dose optimisation at a national level. This part of the study formed the foundation for the study with the other sections building on the methodology used in this first section.

The question on automated tube current modulation (ATCM) which can reduce doses between 35 and 60% had the most incorrect answers (Foley et al., 2013). This is an area that is universally not fully understood by respondents and may be since it is a fairly new technical advancement to CT scanners and supporting the fact that respondents thought they required more education. The results matched the previous published study with 92% answering that ATCM can be influenced by centering correctly compared with 85-90% in the previous published study; 57% correctly answered the section on the use of ATCM in the presence of metallic implants which compared with the previous published study of 52% for radiographers and 77% for radiologists.

The participants felt that education would support them with advancing technology, often new systems are commissioned with initial training given but due to staff shortages and the need to reduce waiting lists all CT staff are unlikely to be timetabled to receive initial application training. This means that on-the-job training occurs which, as pointed out by the respondents, can lead to radiographers who train not having enough knowledge to produce optimum exposure parameters.

Some radiographers felt that undergraduate training should be more uniform. The HCPC and SoR already have governance over the training syllabus for UK radiographers. Postgraduate training is more comprehensive and enables radiographers to use their learned skills to research new techniques and critically evaluate any changes in practice.

Regular continuing CT focused updates was favoured among respondents, and this was probably the most achievable way of providing education and training for radiographers. If training sessions were arranged in the department, radiographers could draw on staff with specialised knowledge within the hospital, these could include medical physics experts (MPE), radiologists and invited speakers.

Informal training within the department is usually from radiographer to radiographer. CT is a fast-paced modality (both in the time available for scanning and in the changes to technology) and with few radiologists available due to the great shortage in their profession and their physical remoteness from the CT scanning area, they are unlikely to be available for discussions in the department.

Although UK radiographers have knowledge of exposure parameters, these feel that further training/education will empower them to optimise patient doses effectively. There was no consensus on how best to gain further education in this field, but five themes were identified which included standardised training at undergraduate level, postgraduate training, on-the-job, CT focused CPD or manufacturer's training. These themes will be explored more deeply in the further phases of this study.

4.6 Limitations

This study involved small numbers so results from this study may not represent opinion at a national level.
This study was at the start of the PhD and collaborative working recommendations may have been implemented in more departments now (Chell, 2016).
The Society of Radiographers was very helpful but on reflection I think that twitter and other communication via social media would have helped with the response rate.

4.7 Robustness and external validity

Major, V., Ryan, S., O'Leary, D. *Radiographer's knowledge of exposure parameters in Computed Tomography (CT) scanning: Is radiation dose being optimised?* Oral presentation, Health and Social Work research conference Hatfield 2016

Major, V., Ryan, S., O'Leary, D. *Exploring optimisation of patient dose during CT scanning.* Oral presentation and poster presentation, ECR Vienna 2017

Major, V., Ryan, S., Letchford, T., O'Leary, D. *Exploring patient dose optimisation in Computed Tomography (CT) scanning.* Poster presentation, UKRC Manchester 2017

Major, V., Ryan, S., O'Leary, D. *Exploring patient dose optimisation in Computed Tomography (CT) scanning.* Poster presentation, Health and Social Work research conference Hatfield 2018

4.8 Mapping the content of this chapter to the aim and objectives

The Aim of this study is to identify training requirements for UK CT radiographers regarding specifically social, clinical, and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation. This chapter partially met the aim, since it reviewed the current knowledge of CT parameters and their influence on patient dose and image quality amongst UK radiographers. Training needs were identified in this group of respondents. Educational factors were considered in this chapter.

This chapter met the following objectives:

- To explore radiographers' knowledge of exposure parameters and view on education using a cross-sectional methodology
- using appropriate methods of analysis compare and contrast data with evidence base
- discuss combine and contrast emerging themes
- document the findings accurately and coherently for dissemination.

Chapter 5- Systematic review training and education

5.1 Introduction

Diagnostic radiography is an ever-expanding profession, where state registered professionals work directly with patients, families, carers, and service users from pre-conception to grave (Society of Radiographers, 2021a). Under NHS England's Diagnostics Recovery and Renewal plan (2020) the role of the diagnostic radiographer is due to be remodeled to accommodate new diagnostic hubs to provide scans to tackle ever increasing waiting lists, as well as continuing with the current workload. Diagnostic radiographers are expected to provide patient centered care as well as being the interface between technology and people, which includes the safe use of radiation (Society of Radiographers, 2021a). It is hard to comprehend the range of technical skills diagnostic radiographers require alongside the demands placed on them in the clinical environment (Society of Radiographers 2021a). Diagnostic radiographers need to be educated to perform this challenging role to empower them to practice safely and effectively in the clinical environment. Effective training in computed tomography (CT) is particularly important due to the large radiation dose to patients and the general environment, 25% of the average population radiation dose in the western world is attributed to CT scanning (Stowe et al., 2020). The International Atomic Energy Association (IAEA) are aware of the variability in CT scanning protocols due to lack of understanding of CT technical factors, they now advocate that CTSimulators (CTSim), which are educational software allowing users to set CT parameters, should be used to optimise dose and observe the effects of the changes on image quality (IAEA, 2019). Approximately 50% of undergraduate learning is in the clinical environment, so it is important to understand how learning occurs in the clinical environment (Society of Radiographers 2021a). There is limited pre-registration CT experience for diagnostic radiographers due to the lack of capacity for CT scanning with the UK, in 2017, being ranked the lowest of 23 Organisation for Economic Co-Operation and Development (OECD) countries for scanner provision, meaning all UK CT scanning departments are extremely busy with over-worked staff (NHS England 2020).

Undergraduate courses provide a foundation of skills and knowledge for radiographers, but it is recognised that the skills and knowledge gained pre-registration will be insufficient to support their future careers (Wareing et al., 2017). At undergraduate level diagnostic radiographers are taught in both the academic environment and the clinical environment whilst undertaking clinical placements. Students can be assigned to one or more clinical sites during their undergraduate studies. Whilst attending the clinical placements the students are supported by links to the university such as practice educators or clinical tutors and by staff in the department. Clinical staff normally provide feedback to the student on their clinical experience, but it is likely that students work with several members of staff every week. Radiographers must meet the HCPC professional standards and cover all the curricula which is accredited by the Society and College of Radiographers (HCPC 2013; SCoR 2013). There is some dispute that the current curricula are fit for purpose for all the facets of a diagnostic radiographer's role (Sloane and Miller, 2017).

Radiographers need to meet the graduate attributes to perform non-contrast CT head imaging by the end of their undergraduate course although it is unlikely that they will be able to use these skills immediately post-registration, extensive departmental training may be required before the newly qualified radiographer is deemed competent to work in an imaging department (Sloane and Miller, 2017). Post-registration radiographers need to familiarise themselves with the department and undertake projectional imaging in the main department, accident and emergency, theatre and on the wards with portable equipment. CT training would normally occur after the initial training, and technology in the department may be different from the clinical environments the newly qualified radiographer trained in.

The qualified radiographers with experience in CT scanning need to be supported to train less experienced members of staff. Wareing et al. (2017) explain that there is a move away from technical instruction to a reflective approach or critical reflective practice but in ever evolving cross-sectional modalities, radiographers may need technical instruction. Clinical scientists and radiologists can also provide CT training sessions to disseminate the aspects they specialise in.

This review sets out to examine the current literature to explore an appropriate method of training and education for CT scanning in the clinical environment and whether training of skills from other professions can contribute to the effective training of radiographers.

5.2 Method

This is a narrative review producing a synthesis of primary peer reviewed studies (Greenhalgh et al., 2019). The problem to be addressed for the systematic review was accessed and key structured questions were identified (Pati & Lorusso, 2018). PICO (Population, Intervention, Comparison, Outcome) is a specialised question development framework used in evidence-based medicine to form the question to be investigated, although this is useful for clinical studies it was felt that this framework was not ideal for this mixed method study, and it was deemed inappropriate to use it to form the question in this systematic review. Other specialised frameworks were investigated since it as important to develop a formulated focused question for this review (Eriksen & Frandsen, 2018). PEO (Population, Exposure, Outcome) and SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research type) were accessed for their suitability. PEO was concise and was designed for qualitative research, SPIDER was developed for mixed method or qualitative research which compliments the study but was not appropriate for the systematic review (Doody and Bailey, 2016). The general research topic was the most appropriate education the clinical environment for radiographers working in CT scanning and PEO was used to formulate precise key questions with 'Population' being the focus of the question, 'Exposure' being the issue and 'Outcome' being what needs examining (Eriksen & Frandsen, 2018; Medical University of South Carolina (MUSC) Libraries, 2021).

5.2.1 Using the PEO framework

Population: the question is focused on CT radiographers in the clinical environment,
Exposure: the influence of some CT exposure parameters is not well understood and there is a need for ongoing education (Foley et al., 2013),
Outcome: how to deliver effective training will be explored.

The structured key questions:

What is the most appropriate method of training and education for CT scanning in the clinical environment?

Are models of technical skills training from other professions transferrable to CT scanning?

How can the training/education be delivered?

Secondary questions

What emotional-social factors affect the radiographers learning experience in the clinical environment? (*To be considered in chapter 6*)

Do social interactions in the clinical environment have an effect on radiographers' ability to learn? (*To be considered in chapter 6)*

The 2020 statements from 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' statements '(PRISMA, 2021) were used for planning and conducting the systematic review, making sure all recommended information was captured. Using the PRISMA statements provides transparency indicating why the review was done, how it was done and what was found (Page et al., 2021).

5.2.2 Ethical considerations

Formal ethical approval was not required from the University ethical committee because it is a secondary study using published sources (University of Hertfordshire, 2022).

5.2.3 Data sources and search strategy

The search was conducted on EBSCOhost, two data sources were searched (PubMed, CINAHL) from January 2015 to end 2021 using four concepts: (1) Training, education, technical, (2) Workplace, In-house, on-the-job, (3) Medical, Allied Health Professional, Radiographer, Healthcare, Hospital, (4) Medical imaging, radiographer, CT, Computed tomography, radiography. Other literature was found using an ancestry and snowball approach, Google Scholar, Radiography (journal) and grey literature were searched (Wareing et al., 2017). Key words and Boolean operators are listed below in the summary table.

Table 5.1 - *Summary of the search filters employed*

Dates: Jan 2015-End 2021	
Online search databases	PubMed, CINAHL, Google Scholar, Radiography (journal)
Search words and phrase combinations	• "Training OR "education" OR "technical" • AND "Workplace" OR "In-house", OR "on-the-job" • AND "Medical" OR "Healthcare" OR "Hospital" OR "Health facilities" OR "Health Services" NOT School NOT mental health, OR mental illness OR mental disorder OR psychiatric illness NOT COVID* NOT occupational health • AND "Medical*" OR "medical imaging" OR "radiographer" OR "CT"OR "Computed tomography" OR *radiograph*".
Search filter methods	• Boolean operators (AND, NOT, OR) - to apply additional filters between simultaneous multiple filters. • Termination asterisk* used on root of word as wildcard - to broaden search to include various endings and spellings • Brackets - to make sure no unrelated terms are included • Quotations - to make sure whole phase is searched to avoid loss of meaning

(Adapted from Wareing et al., 2017)

5.2.4 Eligibility criteria

The following main inclusion criteria were used: Radiographers, Allied Health Professions/ Medical students, Imaging, Technical roles - health and non-health. The following main exclusion criteria were used: articles written prior to 2015, abstract not available, full article not available, non-English language articles, post-mortem CT scanning, cadaver CT scanning, animal CT scanning, occupational Health, COVID, mental Health.

5.2.5 Data extraction and appraisal of quality

EBSCOhost interface was used because it gives access to a range of databases, e-journals and e-books, Boolean/phrase could be searched, and a history of the searches is recorded. Thirty articles were selected using the search criteria which included articles from other sources, the PRISMA table below show detail of the search results. Articles were reviewed via the appropriate Critical Appraisal Skills Programme (CASP, 2018) criteria and using scientific rigour graded into good, moderate, or weak.

Data were extracted into a data synthesis table. Twelve articles were used for the synthesis, nine quantitative, one mixed method and two were quantitative. The review articles were not used in the synthesis but were used elsewhere in this chapter.

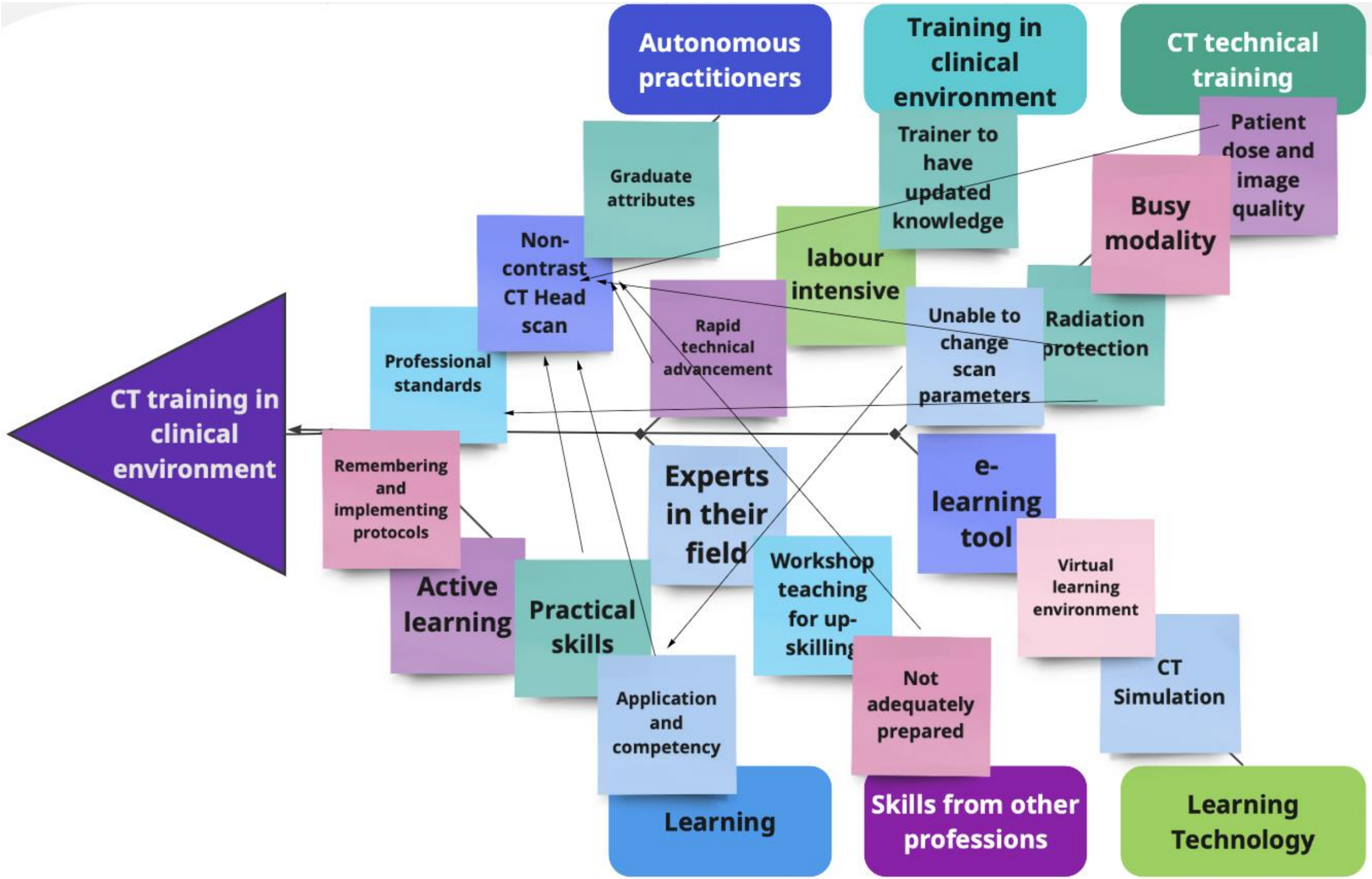

Figure 5.1 - *Diagram of the main sub-themes identified from the literature*

5.3 Main findings

Direct evidence on Computed Tomography (CT) was sparse but there was relevant evidence on radiography training and skills training from other professions in the working environment.

Table 5.2 - *PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and other sources*

(Page et al., 2021)

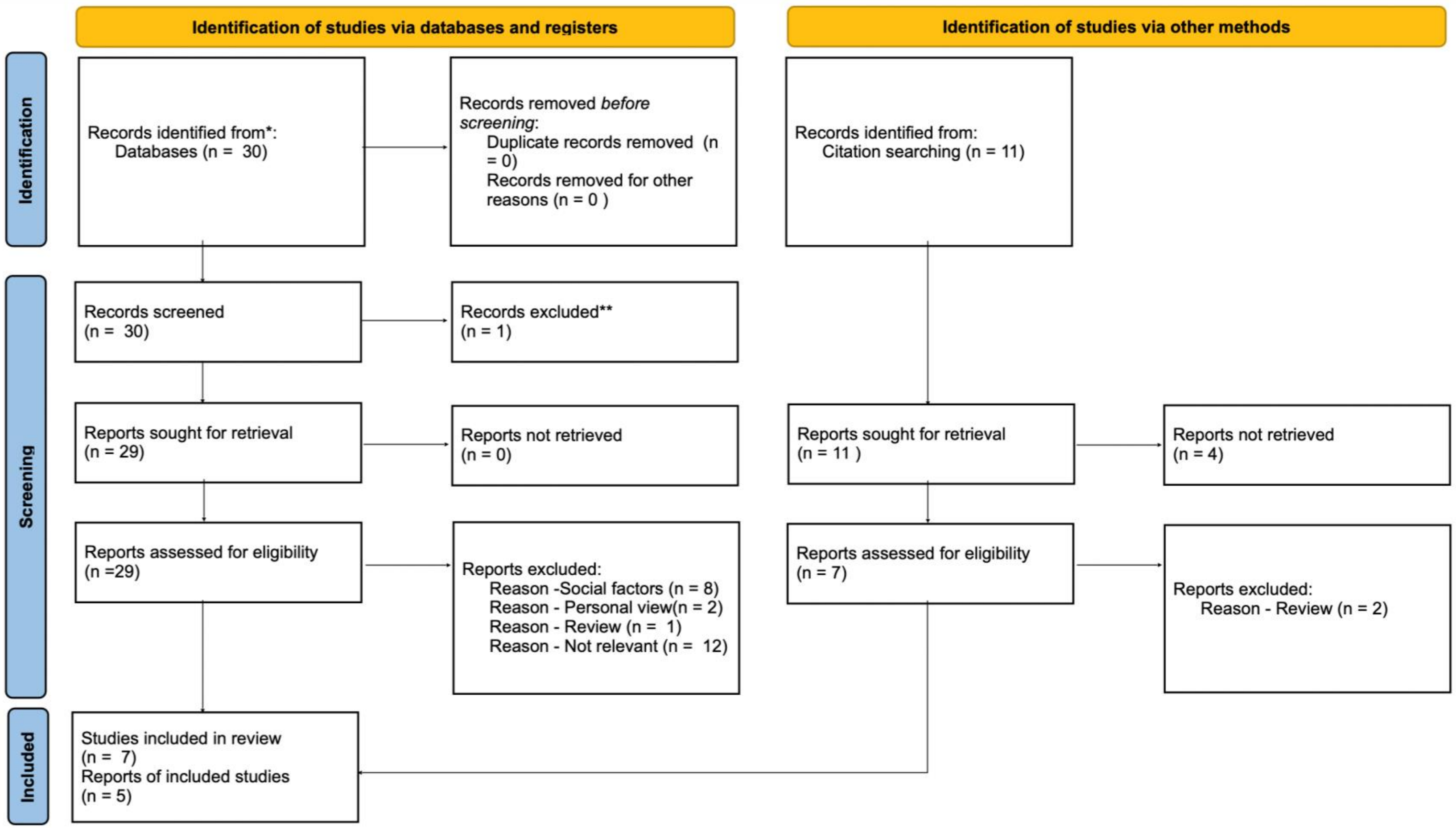

Table 5.3 – *Data synthesis tables*

Author (year) country or area	Aim	Study design	Number	Participant	Summary of results	Study limitations
Sa dos Reis (2018) *Europe*	To compare radiography curricula, teaching/learning strategies, skill development, clinical practice outcomes, and research development delivered by four European educational institutions.	Two phases: 1. Curricula analysis, using observational grid. 2. Questionnaires to 2 groups, teaching staff and final year students. Descriptive and thematic analysis.	Four European educational institutions teaching staff 78 students	demographics	Students felt that technical, practical and communication skills were most important. Teaching staff felt that critical thinking should be added to important skills. Student experience in radiography and CT very good and MRI average in UK and good in other countries. Students felt that research work contributed to critical thinking.	Not stated
Mc Inerney & Baird (2015) *Australia*	Review of students' perceptions of critical thinking teaching approaches used within the undergraduate course.	Mixed methods using a semi-structured peer reviewed survey. Five point Likert scale and open-ended questions. Descriptive and thematic analysis	40/101 students	3rd and 4th year radiography and medical imaging students	Establishment of an audit trail for the educational activities in use within radiography programs can facilitate the acquisition of evidence- based and reflective practice amongst students.	Suboptimal response rate. Students had to recall information taught in first year to answer survey when they were in their final year.

Author (year) country or area	Aim	Study design	Number	Participant	Summary of results	Study limitations
Qureshi et al., (2019) *UK*	Clinical assistantships support UK medical students making the transition to postgraduate practice as doctors. This paper describes a method of teaching clinical referrals	Written evaluation by participants. No formal thematic evaluation.	96/108 (88.9%) participating students. 24/24 faculty members	Final year medical students. Faculty members	Students and faculty members particularly valued the realism of making authentic calls to unseen clinicians, the fidelity of simulated referrals and constructive feedback. They considered this excellent preparation for making referrals in the workplace.	Established validated questionnaire not used. No evidence learning retained to positively affected practice.
Selzer et al. (2015) *UK*	This study aimed to develop a near-patient, e-learning tool and explore student views on how utilization of such a tool influenced their learning.	2 pilot studies. Focus groups with thematic analysis.	Four focus groups, 17 participants. 2x pilot studies.	A single year group of medical students at a single hospital	Clinical e-learning tools are poised to become more commonplace and provide many potential benefits to student learning. Incorporation of technology into clinical encounters requires specific skills which should form an integral part of primary medical training.	Volunteers are more likely to be interested in the e-learning tool. Single set of students from single hospital. One of the pilot studies was used for triangulation.

Author (year) country or area	Aim	Study design	Number	Participant demographics	Summary of results	Study limitations
Sloane & Miller (2017) *UK*	Critically evaluate the fitness for purpose of newly qualified diagnostic radiography	Qualitative, grounded theory approach. Thematic analysis	20 radiology managers	N 1⁄4 20 department heads (male 1⁄4 5; female 1⁄4 15) (geographically) across N 1⁄4 20 trusts N 1⁄4 19 worked within the public sector and N 1⁄4 1 within the private.	The results indicate the role of the radiographer is now in a state of flux and challenge radiology managers and educators to design curricula and career structures which are better matched the role of the radiographer in the very rapidly changing technological, organisational and social contexts of modern society.	Not stated
Couto et al. (2017) *EU*	Identify the commonalities and discrepancies in national regulation of radiography	Descriptive cross-sectional, non experimental, qualitative.	27 national competent authorities	National competent authorities from:- Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden & UK	Profession not regulated ion one country. 21% regulate different professions for different specialisms. All countries define education as a requirement but academic level varies from secondary school to Master's degree. Educational subjects covered shown great heterogeneity. Only 26% define subjects in terms of competencies.	Lack of information available from competent authorities.

Author (year) country or area	Aim	Study design	Number	Participant	Summary of results	Study limitations
Stowe et al (2020) Europe and Canada	To test a newly developed simulator 'CTSim' for effectiveness in teaching and learning.	Two phases; 1. used a test-retest methodology with two groups, one group Simulation based learning and one which did not. 2. tested for changes when the same intervention was introduced as part of an existing CT training module.	phase 2 - 90 students	Pilot- academics numbers not known Phase 1- summer school participants Phase 2 - BSc radiography students	Statistically significant improvement mean scores 58% to 68% (P < .05) for students who experienced the intervention against no change. Phase 2 saw mean scores improve statistically significantly 66% to 73% (P < .05) following the application of the intervention as an active learning component. The use of the CTSim simulator had a demonstrable effect on student learning when used as an active learning component in CT teaching.	none listed
Morawetz et al (2021) *USA*	The contribution that 'worker trainers' make towards safer and a healthier work places.One of the elements that contributes to the creation of a comprehensive approach to improving the workplace environment.	Surveys in 2016 & 2018. Quantitative.	27/27 2016 23/29 2018	International Chemical Workers Union Council Consortium (ICWUC) workers	The roles that worker trainers play when returning to the shop floor after classroom training. One of many elements necessary for better outcomes and a safer work place.	The length of time a person has been a worker trainer had an influence on how questions were asked has not been assessed.

Author (year) country or area	Aim	Study design	Number	Participant	Summary of results	Study limitations
Davey et al. (2020) *USA & India*	The evaluation of an Indian postgraduate diploma in emergency medicine	Online survey. 5-point Likert scale. Descriptive statistics.	56/108 students who completedo n the course	45 male 6 female 5 unknown gender Madurai 35, Chennai 8, Delphi 6, Kerala 7.	Students reported improvement in their comfort of performing all procedures taught in the course. 88% said it was important to meet the demands of their job. 98.1% said skills and knowledge important to their current practice.	Small sample size and our sample was restricted to four sites, our results may not be generalisable to other similar programmes offered in India
Shah et al. (2016) *Canada*	This study compares mixed versus blocked practice, after the initial teaching of concepts, among medical students using online self-study chest X-ray (CXR) modules.	Participants were divided into 2 groups. One group completed the mixed modules and the other group completed a blocked module. The content of both modules was the same. Evaluated twice, once immediately after training and other after 2 weeks. 20 novel Chests X-rays shown to each group. Tests were scored.	58 medical students in years 1-3. Sample size 25 per group.	Medical students	Performance after mixed practice was similar to that after blocked practice	May not be directly comparable with other research in the area of mixed versus blocked practice because learning of mathematical problems or language may differ from those involved in the learning of visual tasks.

Author (year) country or area	Aim	Study design	Number	Participant	Summary of results	Study limitations
England et al. (2016) *EU*	Understanding of patient safety within radiography education across Europe.	Online survey, descriptive and thematic analysis	33/54 from 19 EU countries	Academic institutions from :- Austria x2, Belgium x2, Czech Republic x1, Denmark x1, Estonia x 1, Finland x 4, France x1, Greece x1, Ireland x1, Italy x2, Latvia x2, Lithuania x 1, Malta x1, Netherlands X2, Norway x1, Portugal x 3, Slovenia x1, Sweden x 2 & UK x4.	Patient safety covered well across curricula. Not taught at an advanced lev el; Radiation protection x 5/33 & dose optimisation x12/33. Most patient safety related teaching in clinical environment.	Response rate 61.1% lower than previous EFRS survey. Response from 19/24 countries so implications for generalisability of findings. Data from a single point in time. Validity not tested.
Roberts et al. (2018) *UK and Sweeden*	To explore the perceptions of senior medical students in a number of different CLEs	New tool to UK (The four-factor Undergraduate Clinical Education Environment Measure (UCEEM)) used. Cross-sectional questionnaire study. Quantitative.	132/165 final year medical students.	59% female, 41% male. 88% school leavers, 12% mature students.	For opportunities to learn in and through work experience emergency medicine (EM) was reported the most positively. Medicine for the Elderly(ME) was perceived to be the most prepared for student entry. Students reported being well received by staff and made to feel part of the team within General Surgery, EM and ME, but less so in Obstetrics and Gynaecology. .	Length of time since the placements could screw the student's perceptions. Snapshot in time.

This review suggested three key themes and sub-themes (sub-themes shown in Figure 5.1) which will be considered in the findings. The key areas are: current models of training (including sub-themes: training in clinical environment, learning and autonomous practitioner), skills training in other professions, and delivery of training (including sub-themes: technical training and learning technology)

5.3.1 Current models of training

During diagnostic radiography training students attend clinical placements in CT scanning and at qualification diagnostic radiographers are required by their professional standards to complete a non-contrast head scan (HCPC, 2013). During their clinical placement experience students are unlikely to be able to investigate the influence of CT scanning parameters on patient dose and image quality because of the limited experience they have in a busy modality and for safety reasons (Sloane and Miller, 2017; Stowe et al., 2020). Students tend to learn in a passive way recording the process of how to select the correct technical factors for the scans and how to provide patient care in the modality, students are not competent autonomous practitioners pre-registration and must be supervised at all times so their experience is limited (Stowe et al., 2020). Academic teaching lays the foundation of the impact of adjusting CT scanning parameters but in a crowded curriculum, students may not realise its importance and may have forgotten some information by the time they use CT scanners in a practical setting (Shah et al., 2016; Stowe et al., 2020). As established previously, due to the lack of CT provision, departments do not normally have time to allow students to experiment with phantoms in the clinical department, although some UK universities do have CT scanners or virtual CT simulators to allow students to explore exposure parameters (Stowe et al., 2020).

McInerney and Baird (2015) argue that the undergraduate radiography experience should be more than remembering and implementing protocols to enable them to scan but they should learn to think critically. The application of critical thinking is a benefit to radiographers, both pre- and post-registration, to allow them to communicate their thoughts in the clinical environment and critically reflect on their work experience especially in as radiography is an area of rapid technical advancement (McInerney and Baird, 2015). Sloane and Miller (2017), who interviewed 20 radiography managers using qualitative grounded theory approach, agree that cross-sectional medical imaging is undergoing a period of substantial change, with technical advancements, evolving areas and increased scanning numbers, which demands a need for an effective future-proof curriculum. Currently undergraduate education concentrates on projectional radiographic imaging which is out-of-step with the demands of the workplace (Sloane and Miller, 2017).

When 78 students from four European educational institutions were asked what the most important skills required to be a radiographer, they felt that technical, practical and communication skills were the most important to develop, whilst the teaching staff felt that critical thinking and inter-professional skill should be added (Sa Dos Reis et al.,2018). England et al. (2016) specially examined the teaching of patient safety across Europe, a key aspect of the undergraduate curriculum, which could be included in the technical skills mentioned in Sa Dos Reis et al. (2018) study, although it is not clear from the article. England et al. (2016) had a 61% response rate from 54 educational institutions which revealed that curricula covered patient safety topics extremely well, although radiation protection and dose optimisation were not being covered at advanced levels. England et al. (2016) also confirmed that patient safety is being taught in the clinical environment, which is reassuring. Couto et al. (2017) evaluated educational requirements across the EU by inviting the 27 national competent authorities to identify the legal requirements to practice radiography, they concluded that experience in the clinical environment as an undergraduate was a requirement of 11 of the countries. In the United Kingdom (UK) the clinical training was not specified if it met standards of proficiency. Clinical practice in the UK is currently in a state of flux with rapidly changing technology alongside organisation and social transformations making learning in this environment a challenge (Sloane and Miller, 2017). Students in the UK have a varying amount of time and experience in the ever-expanding clinical environment where important aspects of their training occur, including patient safety, radiation safety and optimisation, with limited experience in cross-sectional imaging (England et al., 2016; Sloane and Miller, 2017; Couto et al., 2018). This begs the question, are skills taught effectively in the clinical environment currently?

5.3.2 Skills training in other professions

Key components of skills training do not need to occur in the workplace environment, there is an opportunity to teach the key foundation for skills in an interactive workshop environment. Several papers have individually targeted delivering single aspects of skills training in-depth. The professional role in the clinical environment is made up of thousands of skills and tasks which include technical, legal and radiation safety. Effective training of these skills is paramount to a diagnostic radiographer's training. Good quality education in the clinical learning environment (CLE) is important to medical, allied health and nursing students since educators in the CLE may have a greater influence than lecturers in the academic field (Roberts et al., 2018). Students may perceive educators in the CLE as 'experts' in their field or more current than academic staff, so are more likely to have an impact on the student. Roberts et al. (2018) believe that the CLE can affect the way a learner progresses and can affect their practice after registration. It is difficult to give all students equity of learning in the CLE, they will not all have the same experience due to several key differences such as clinical cases which present during their time in each area, their relationship with their trainers, and their supervisor's ability to train (Roberts et al., 2018). Experience in the CLE will be variable but should have the same broad opportunities (Queshi et al., 2019).

The General Medical Council (GMC) in 2009 found that half the medical graduates did not feel that they were adequately prepared for their practice and thus introduced an undergraduate assistantship (Queshi et al., 2019). The assistantship involves undergraduates attending a clinical attachment where they take on most of the duties of a newly qualified doctor. The General Medical Council (2011) explains that the assistantship is placement in one or more NHS Trusts towards the end of the undergraduate course to prepare medical student to start practice as an FY1 (fourth year medical student employed by an NHS Trust on a training programme). Diagnostic radiographers tend to have a more structured clinical programme as undergraduates but are autonomous practitioners as soon as they qualify (Sloane and Miller, 2017). Queshi et al. (2019) targeted important skills and provided workshop teaching to explore the skills in detail, giving a feeling of reality that enables undergraduate medical students to transition to postgraduate practice. All the faculty members

(100%) and 89% of the undergraduates participated in the evaluation of the training, thematic analysis was performed by the researchers, the workshop was considered excellent preparation for the workplace and valued the realism and the authenticity (Queshi et al., 2019). Davey et al. (2020) realised that most emergency care in India is performed by non-specialty trained doctors and they realised that providing skills training would improve the ability for doctors to respond to acute illness. Unlike in the UK where a four-week skills and clinical placement course is provided, the course in India was delivered over a year (Queshi et al., 2019; Davey et al., 2020;). Davey et al. (2020) used a five-point Likert scale to evaluate feedback, respondents came from four sites in India, 56/108 participants responded, 88% felt the course was important to meet the needs of their job such as airways management, central venous access, lumbar puncture which are considered essential skills in emergency medicine. The study in India concentrated on up-skilling already skilled workers so they could perform core tasks in a competent manner whereas the UK study was giving pre-registration medical students experience and skills training in the CLE. Both studies relied on mentors in the CLE but supplemented the CLE with interactive workshops.

Morawetz et al. (2021) examined the contribution the ‘Worker Training Program’ made towards improving safety by educating staff in the classroom and when they return to the shopfloor after training. Employees selected for the ‘Worker Training Program’ are offered peer support as well as classroom training, leading to less contradictions between the academic and shop-floor worlds (Morawetz et al., 2021). The final year medical students in Roberts et al. (2018) examined the opportunities to learn through work experience using an undergraduate clinical education environment measure questionnaire, translated from Swedish. The survey was completed by 84% of students and compared the four departments the students were placed in via a Likert scale, with obstetrics and gynaecology giving low scores for experiential learning, opportunities to learn in and through work supervision, and preparedness for student entry (Roberts et al., 2018). The authors felt that a high rating department would allow for opportunities to learn from work experiences, students would feel included, staff in the department would be prepared, and students would benefit reflectively from departments that allow them to act autonomously (Roberts et al., 2018). It is important for learners in a work environment to have a supportive learning environment with trainers who give feedback and allow the trainee to learn by applying the underpinning academic theory (Roberts et al., 2018; Morawetz et al., 2021). The importance of being taught by a competent, confident, supportive, knowledgeable trainer should not be underestimated.

The four papers discussed in this section were studies using a survey tool methodology. The articles lacked content and robust methodology, but did explore the difficulties of delivering skills training, which could be transferable to radiography. If the ethos of providing bespoke skills training is transferred to radiography, then there could be a four-year undergraduate course with the fourth year providing cross-sectional imaging skills training mostly in the CLE, pre-registration radiographers would need to keep up their competencies in projectional radiography at this time (Sloane and Miller, 2017). The four-week assistant course for medical students is akin to the preceptorship in cross-sectional imaging mentioned in Sloane and Miller (2017), which has been introduced in UK departments to add CT skills training and competency to bridge a gap in training in this area. Roberts et al. (2018) and Morawetz et al. (2021) were concerned about how the trainers are trained and how easy it is to learn in the work environment.

5.3.3 Delivery of training

Providing trainers in the clinical environment to update staff, mentoring new staff and providing preceptorship is labour intensive and requires the trainer to have updated knowledge. Currently Practice Educators facilitate education in practice in collaboration with clinical and academic colleagues (Society of Radiographers, 2020a). The rapid technical advancements, diversity of imaging and unprecedented demands in radiography means that a team of “educators” are required to teach clinical skills along with updating their own academic knowledge; the problem of clinical teaching is further exacerbated by the fact that some departments do not have dedicated practice educators with this teaching and personal learning within their remit. Clinical staff as previously mentoring students without the facilitation of Practice Educators therefore find this far more difficult to achieve with any uniformity of provision.

Radiography students attend the same CT lectures at the same time during the academic year so a student may learn about CT dose optimisation within the course but attend CT clinical placement later in the year, thus much of their knowledge from the lecture will not be reinforced by participating in the practical aspects. Consequently, some information may have been forgotten, and students will not get maximum educational benefit from the CLE (Selzer et al., 2015; Shah et al., 2016).

Selzer et al. (2015) in a qualitative study, interviewed a cohort of 17 medical students in four focus groups; they experimented with a near patient e-learning tool and found that the e-learning tool had the potential to integrate workplace learning and promote contextualised learning. In this study the e-learning tool was moved to the patient and the participant had a rapid revision of the medical condition before using the e-learning tool to interview the patient, CT radiographers would not need an e-tool at the patient's side but would benefit from CT Simulation (CTSim) for learning skills in the CLE. Stowe et al. (2020) divided 90 radiography students into two groups, one group experienced a CTSim learning intervention and the other group did not, test-retest methodology was used. Stowe et al. (2020) identified statistically significant improvement of mean scores from 66% to 73% ($P < .05$) for students who experienced the CTSim intervention compared to no change in scores for the control group. Stowe et al. (2020) concluded that the use of the CTSim had a demonstrable effect on the student radiographers' learning when used as an active learning component in CT teaching. CTSim could be the e-learning tool use for proactive learning especially since it can be available via the student's university virtual learning environment (VLE). CTSim can be available in CT dose management software packages, where radiographers can input hypothetical exposure parameters and see the effect on radiation dose and image quality and compare it to the actual parameters used in the CT acquisition. e-Learning tools can supplement prior learning, give students confidence in clinical skills, and encourage students to utilise workplace learning opportunities (Selzer et al.,2015; Stowe et al.,2020).

Clinical practice occurring over a long period of time in blocks helps individuals store information, so the current layout of undergraduate clinical practice for radiographers is set out in such a way that helps students to store information in long term memory

(Shah et al., 2016; Society of Radiographers, 2021a). Students learn in different ways at different speeds, any content online that can be re-played at a student's convenience is likely to enhance the student's learning since they can learn at their own pace. Shah et al. (2016) examined chest X-ray teaching to medical students, 58 medical students participated. One group of students completed the course in a block for each pathology, while the other group completed modules with a mix of pathologies, each group was evaluated, by tests consisting of 20 X-rays, immediately after training and two weeks after training, the tests were scored. The researchers found no difference in the scores from the two groups, the number of participants were small and the number of X-rays in the tests were small, but it did demonstrate performance after both types of teaching was similar (Shah et al., 2016).

5.4 Discussion

All training has a cost, but Wareing et al. (2017) found that being short of time is the main barrier to engaging in education in the imaging department. These authors explained that time had two elements 'home time' and 'work time' and currently with the increased workload radiographers felt that they needed to protect their 'free time' for relaxing and leaving less time for education outside their 'work time' (Wareing et al., 2017; Society of Radiographers 2021a). Education in the workplace is needed more now than ever due to the complexity of diagnostic imaging meaning that newly qualified radiographers are finding it harder to maintain competency in more than one modality, departments are dedicating time to induction programmes, some of them running for twelve weeks (Sloane and Miller., 2017).

Stowe et al. (2020) reveal that students have little opportunity to change exposure parameters whilst in the department and this probably holds true for most of the radiographers in the department. Going forward, with CT scans predicted to increase 100% in the next five years, there is likely to be more pressure on clinical placements with the demand for more radiographers requiring more training places, which will give students less opportunities to train in cross-sectional modalities (Nightingale, 2016; Society of Radiographers 2021a). Without active learning radiographers may find it difficult to retain information about adjusting exposure parameters because their knowledge base is solely theoretical and does not involve critical thinking (McInerney and Baird, 2015). Radiation protection and patient safety is being taught in undergraduate programmes, which is a key part of the radiographer's role (England et al., 2016).

Currently most CT skills are being taught in the clinical environment, but this training is not producing newly qualified radiographers who are competent in cross-sectional imaging (Sloane and Miller., 2017). Medical students seem to experience a less formal CLE timetable when compared to radiographers, and many felt unprepared for practice (Queshi et al., 2019). Assistantship programmes have been setup to allow medical students to learn clinical skills, as well as working in the CLE they attend tailored workshops on aspects of their clinical work (Queshi et al., 2019). Davey et al. (2020) explained that doctors working in emergency departments were not trained in clinical skills since the role of emergency physician was not a discrete role. The doctors working in the emergency room were able to learn and practice skills in a simulated clinical environment and gain competencies before returning to their work in the emergency department (Davey et al., 2020). Initial teaching of the background of a skill and its practice of its application are integral components of learning, so the undergraduate curricula is well set out in general to enable skills learning (Shah et al., 2016).

Where there are pressures on learning skills in the CLE such as cross-sectional imaging, radiographers could benefit from attending focused workshops for skills that are difficult to explore in detail in a clinical environment (Sloane and Miller., 2017; Queshi et al., 2018).

Online interactive learning and e-learning tools such as CTSim may help with blended learning and enable large numbers of students and staff to learn while keeping the teaching tools updated from a centralised point.

Learning does not happen in isolation, one of the opportunities available in the CLE is to acquire knowledge from other professions. Kent et al. (2017) found that safety focused inter-professional discussions and reflections in the CLE contributed to improved safety awareness. This will be discussed in the next chapter.

5.5 Conclusion

The undergraduate curriculum with integrated clinical practice over three years is a good model of education, diagnostic radiography has become more complex and is delivered in a constantly changing busy environment. It is hard to learn clinical skills in cross-sectional modalities, especially in the pressurised CT department. How do radiographers feel they want to learn skills?

The next chapter will look at the psychosocial side of learning as a radiographer.

Chapter 6- Psychosocial factors in the clinical environment

6.1 Introduction

This chapter investigates the psychosocial factors which include social education and social interactions within the clinical environment. The literature to be reviewed was identified from the systematic review in the previous chapter.

Student diagnostic radiographers spend approximately half their time in the clinical environment since radiography (Society of Radiographers 2021a). During this time, they are exposed to a multitude of psychosocial and emotional interactions within the clinical environment over time they develop social and problem-solving skills to enable them to work in their clinical placement (Holmström et al., 2022). Emotional wellbeing is a factor enabling student radiographers to participate in experiential learning in the clinical environment, they have a requirement learn social and emotional skills alongside educational and technical skills during their progression to competent radiographer (Westbrook, 2017; Jeyandrabalan et al., 2022). Learning comprises of many different factors, learning in the clinical environment is even more complex and not completely understood with individual learning preferences, and emotional intelligence indicating a person's ability to learn being factors (Shatalebi et al., 2012). The link between high emotional intelligence and academic success is dependent on the subjects being studied and a link has been discovered in health sciences, although further research is required to understand the mechanisms (Shatalebi et al., 2012; Petrides et al., 2018). Developed social and emotional skills are required to navigate a clinical environment, to make competent judgements and to interact with staff and patients (Benson et al., 2010). Emotional intelligence is sometimes known as emotional-social intelligence and described as a synthesis of social and emotional proficiencies, skills and actions that enable people to understand themselves and others, how to relate to them and cope with the environment around them (Cleary et al., 2018).

Emotional skills are required in the clinical environment for pre- and post-registration radiographers because the experience in the clinical environment is unplanned and unstructured, requiring coping mechanisms (Mifsud et al., 2015). In clinical practice critical thinking is an essential skill, providing transformative learning leading to better patient outcomes and is especially important with rapidly advancing technologies used in cross-sectional imaging modalities (McInerney and Baird, 2015). Complex, ever changing technology in their clinical environment requires staff to adapt, problem solve and interconnect with other healthcare professionals (Clark and Hoffman, 2019). The clinical environment is challenging for students, requiring them to have skills to equip them be resilient during clinical placement which is known to effect emotional welling (Jeyandrabalan et al., 2022). Students should receive a holistic focus during pre-registration and transition to a post-registration radiographer to allow them to navigate emotions in the clinical environment (Jeyandrabalan et al., 2022). Positive social interactions are required to cope with the intense pressures in CT scanning because it is a highly pressured and demanding modality (Nightingale et al., 2021).

Some experienced practitioners are unable to make the connection between theory and practice leading to an inability to teach students and newly qualified radiographers in cross-sectional imaging modalities especially since there is an inconsistent matching of supervisors to trainees due to the busy nature of the clinical environment and shift patterns of radiographers (Westbrook, 2017). The unpredictable nature of the clinical department can leave students feeling uncomfortable being unable to integrate with busy radiographers concentrating on their work (Mifsud et al., 2015). Students in the Mifsud et al. (2015) study felt they required frequent and effective supervision, although they acknowledged that some of the team did connect with them and that all radiographers were providing positive role models when communicating and caring for patients. An effective clinical learning environment should promote inclusivity and recognise individual characteristics to establish a co-creative space (Razack and Philibert, 2019).

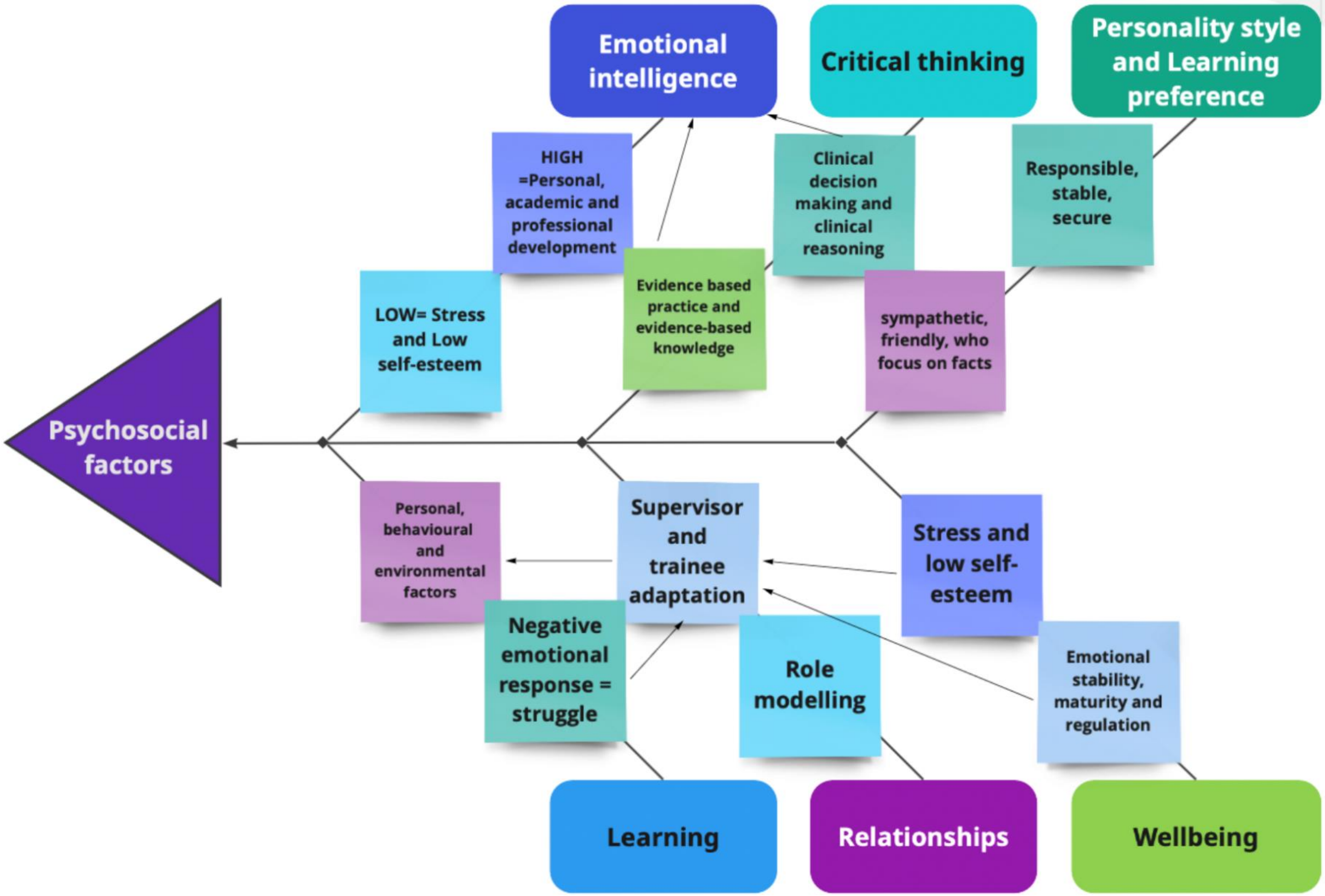

Figure 6.1 - *Diagram of the main sub-themes identified from the literature*

6.2 Key questions for social education

What emotional-psychosocial factors affect the radiographers learning experience in the clinical environment?

Do social interactions in the clinical environment influence radiographers' ability to learn?

Table 6.1 - *Data synthesis table*

Author (year) country or area	Aim	Study design	Number	Participant demographics	Summary of results	Study limitations
Olmos-Vega, et al., 2018, *Colombia & The Netherlands*	How do residents and supervisors develop a shared understanding to accomplish a common goal.	Constructivist, grounded theory	18 supervisors , 11 residents	supervisors - varying years of teaching experience, residents - different training levels	Achieved a shared understanding by adapting to one another. Resident-supervisor dyads, engaging invidious adaption patterns. Creation of a working repertoire.	Overlooked aspects of supervisory dyads.Risk of participant reactivity.
Dungey and Yielder, 2017 *New Zealand*	Investigating learning styles and personality types and ascertain whether there is a pattern evidenced for this group and compare this (RT) and Medical Imaging groups.	Longitudinal, questionnaires (validated tool).	73	First year radiotherapy undergraduates 2014-2016. Predominantly female 61/73	RT students exhibit personality and learning style preferences similar in Introversion/ Extraversion and Thinking/ Feeling to the proportion expected in normal population. Sensing/Intuition and Judging/ Perceiving dichotomies show similarities to medical imaging fell considerably outside expected of normal population.	First three years of five year study.

Author (year) country or area	Aim	Study design	Number	Participant demographics	Summary of results	Study limitations
O'Brien et al., 2020 *Australia*	To identify outside range of generic skills technical and academic achievement impact on work readiness.	Nominal Group Technique	7= AH Director & AH workforce developme nt officer(Gro up 1) 5 =Clinical supervisors (Group 2) 6= AH clinical education support officers and clinical supervisors (Group 3)	Group 1= mean years experience 21 years as AH professional Mean =15 years experience training students and new graduates Group 2= mean years experience 16 years as AH professional Mean = 9years experience training students and new graduates Group 3= Mean years experience 21 years as AH professional Mean =13 years experience training students and new graduates	37 characteristics were judged to be the most important.	None listed
Kaya et al., 2018 *Turkey*	To investigate nursing students' critical thinking dispositions and emotional intelligence as an essential skill, over the course of the undergraduate nursing program.	A longitudinal design	182 student nurses	82% female, 18% male Age range 17-22 years old	No relationship between sub-dimensions of emotional intelligence. Moderate correlation was found in the positive direction between the self-motivation at the beginning of the academic year and critical thinking disposition at the end of the final academic year	Limited to one year group in one university. Small sample

Author (year) country or area	Aim	Study design	Number	Participant demographics	Summary of results	Study limitations
Girin et al., 2021 *Australia*	Investigate factors that contribute to students' reduced wellbeing on clinical placements, and to identify responses to situations that are considered challenging	Mixed methods, online survey	461 students 155 completed surveys returned	5 student cohorts form undergraduate and graduate entry masters DR programs at university of Sydney between 2018 -2019. Over 18, attended at least 1 clinical placement block. First year undergraduate students were excluded.	Support strategies and educational interventions are recommended in order to support students' wellbeing. 4 themes; student role expectations, emotional impact of patient's presentation, interaction with radiographers. Emotional challenges exist in the clinical environment.	Small sample size, one academic institution. Respondents opinions may have been different from non-respondent opinions.
Horsburgh and Ippolito, 2018 *UK*	The study focuses on role modelling as an active, dynamic process, involving observational learning and aims to explore the process involved, including strategies that learners and medical teachers use to support this.	Qualitative, interpretative methodology with one-to-one semi-structured interviews.	6 final year medical students 5 clinical teachers	Final year medical students- no demographics given Clinical teachers from a variety of specialities and teaching experience	Students could identify ways in which they learnt from role models but acknowledged that this was complex and haphazard. They described selectively and consciously paying attention, using retention strategies, reproducing observed behaviour and being motivated to imitate. Students evidenced the powerful impact of direct and vicarious reinforcement. Clinical teachers reported using strategies to help students learn, but these were not always consciously or consistently applied or informed by teachers' understanding of their students' cognitive processing.	• lack of constructive alignment • ability to imitate the actions of others might not be accompanied by underpinning clinical knowledge • unfamiliar nature of obser-vational learning in the clinical settings

Author (year) country or area	Aim	Study design	Number	Participant demographics	Summary of results	Study limitations
Brydges et al, 2020 *Canada*	To find out how residents navigate their exposure to and experience performing invasive procedures in intensive care units. Self-regulated learning.	Constant comparative methodology to analyses data from post-call debriefs with residents coming off shift and later via semi-structured interviews.	29 debriefs 9 interviews 24 trainees	Year-2 and Year-3 residents attending ICU rotation from Mount Sinai Hospital, Toronto Western Hospital, University Health Network	Identified specific SRL mechanisms trainees used to distinguish and navigate possible training trajectories. Trainees become attuned to interactions between personal, behavioural and environmental factors.	Trainees perceptions of their learning which may not align exactly with their actual behaviours and mechanisms. Outsider to collect data.
Sa et al, 2019 *West Indies*	Emotional intelligence is related to empathy and self-esteem	Cross-sectional study, self-reporting questionnaires	460 returned questionnaires	1st year, dental, medical, nursing, optometry, pharmacy and veterinary students. Most 18 year olds. 338 female (73%) 122 male (27%) African 66 (14%) Indian 263 (57%) Mixed/other 131 (29%)	a significant proportion of 1st year students suffer from low self-esteem. More research needed on relationships between self-esteem, emotional intelligence and empathy.	Self-reporting tools can cause social desirability bias. Collected at one point only. More senior students would have more experience a greater level of socialisation.

6.3 Main findings

The literature relating to social skills and interactions in the clinical environment was reviewed, coded and themes were identified. Table 6.1 shows the literature selected for review. This review suggested two key themes which will be considered in the findings. The two key areas are: psychosocial factors, and relationships and their effect on learning in the clinical environment. The sub-themes and their interactions are demonstrated in Figure 6.1.

6.3.1 Psychosocial factors in clinical placements

In common with other healthcare professionals, clinical placements are an integral part of a student radiographers' training allowing a fusion between academic education and practical skills by providing a dynamic hands-on environment where students can learn (Girin et al., 2021). Clinical learning environments offer powerful learning opportunities but can be a challenging experience for students (Olmos-Vega et al., 2018). To be successful in the clinical environment, health professionals require a combination of academic ability and psychosocial factors including emotional intelligence and social skills to effectively participate in the workforce (Sa et al., 2019; O'Brien et al., 2020).

Dungay and Yielder (2017) investigating personality types, in New Zealand, feel that student radiographers experience difficulties during their training with is not correlated with their academic ability and could be associated with the students' personality type. The stress of some aspects in clinical placements can trigger an emotional response in students, which can influence their emotional wellbeing (Dungay and Yielder, 2017; Sa et al., 2019; Girin et al., 2021). Emotional intelligence is important in the clinical environment with high-levels associated with high-levels of personal, academic, and professional development but low levels associated with stress and low self-esteem particularly when first attending clinical placements (Sa et al., 2019). Healthcare professionals and students providing high quality patient care are required to use their critical thinking and emotional intelligence skills to navigate their feelings about patients and their families as well as colleagues (Kaya et al., 2018).

Girin et al. (2021) collected data from 155 diagnostic radiography students in five cohorts enrolled in undergraduate and graduate entry masters' programmes via mixed method survey methodology. Under their 'student role and expectations' theme, in their qualitative data analysis, they described students as feeling challenged by the need to apply academic knowledge in the clinical environment as well as the unreasonable expectations of being proficient in imaging despite their lack of experience causing stress, being in CT scanning from day one was given as an example (Girin et al., 2021). In their longitudinal study Kaya et al. (2018) looked at the relationship between emotional intelligence and critical thinking in nursing students because they felt that these are important traits in the clinical environment, their development being ongoing and enabling clinical decision making, reasoning, adoption of evidence-based practice, and practice-based knowledge and leading to quality in the workplace. The authors considered critical thinking as the link between emotions and intelligence, their study involved 182 students at four time points during their undergraduate course using a critical thinking and emotional intelligence survey tools (Kaya et al., 2018). Girin et al. (2021) believe that there is a relationship between cognitive thought and emotions making people who trigger an emotional response when exposed to difficult situations struggle with learning. O'Brien et al. (2020) identified characteristics of allied health students which were important for their clinical work readiness, selecting three groups they interviewed them to discover the desired characteristics finding that emotional stability, maturity and regulation was important to both the allied healthcare directors' group and clinical educators' group but not to the clinical supervisors' group. Kaya et al. (2018) could not demonstrate a relationship between their participants' critical thinking skills and the emotional intelligence sub-dimensions from first year students to final year students, they did find an increase in critical thinking ability over the four-year time scale but no change in emotional intelligence, they did acknowledge that a link had been found in previously published literature. Kaya et al. (2018) used an emotional intelligence survey, but it was not the conventional Trait Emotional Intelligence Questionnaire, developed by Petrides, so it is difficult to compare their results with other published literature (Petrides, 2009).

Brydges et al. (2020) looked at the active learning process in the clinical environment, believing that a triad of links exists regulating ongoing learning comprising of relationships between, personal, behavioural, and environmental factors. Dungey and Yielder (2017) looked at the personality types of student radiotherapy radiographers and compared them to diagnostic imaging students. Longitudinal survey methodology was used asking 73 students to complete a Myers-Briggs type indicator (MBTI), the authors arguing that MBTI is a relatively stable measure not changing readily and that healthcare workers are likely to score highly in the 'feeling' dimension (Dungey and Yielder, 2017) The dimensions listed in the MBTI tool by the researchers were, 'extraversion', 'introversion', 'sensing', 'institution', 'thinking', 'feeling', 'judging' and 'perceiving', with the eight terms providing four dichotomies and although everybody uses all the dimensions but with different preferences (Dungey and Yielder, 2017). Dungey and Yielder (2017) discovered that radiotherapy and medical imaging students had similar personality types with 'sensing/judging' (responsible, stable, secure characters) and 'sensing/feeling' (sympathetic, friendly characters who focus on facts) being the highest preference, greater than the general population with thinking lower than the general population, the results were not analysed using statistical tests.

MBTI is used widely but there is a lack of empirical evidence to support any links between personality types and demonstrable predictions of workplace performance (Pittenger, 2005). From a theoretical perspective one MBTI preference is no better than another preference and cannot be used to predict academic success, it is best used to inform teaching (Randall et al., 2017). Pittenger, (2005) indicate that performance in the workplace has many complex influences and cannot be predicted from MBTI personality types.

There is a consensus that learning in the clinical environment is complex, involving many factors including learning preferences, emotional intelligence and social skills with low levels leading to stress and low self-esteem and high levels leading to academic achievements (Girin et al., 2021; Dungay and Yielder, 2017; Sa et al., 2019). The next section will look at how personality types and supervision combine when another layer is added to the intricate process of learning in the clinical environment.

6.3.2 Relationships

Training in the clinical environment promotes active learning and is a vital part of radiography training courses (Brydges et al., 2020). For successful workplace learning, commitment and interaction is required between trainers and learners (Olmos-Vega et al., 2018). Symbiosis between supervisors and trainees with different learning preferences and emotional strength is required and their mutual adaptations create learning spaces in the workplace (Olmos-Vega et al., 2018). First year students may have more issues forming partnerships for learning than second- or third-year students, since they have low levels of socialisation in their respective field (Sa et al., 2019).

Horsburgh and Ippolito (2018) explain that trainers become role models in the department and role modelling is an active dynamic process leading to effective learning in an ever-changing unplanned environment. Role modelling relies on two theoretical constructs: people identify with people who hold a position that they desire to hold, and people believe that they can learn skills and behaviours from role models for a particular environment (Horsburgh and Ippolito, 2018). Students are unable to learn in the clinical environment unless they engage with their supervisors successfully, creating a shared understanding which lead to enhanced patient care (Olmos-Vega et al., 2018). For a successful partnership between supervisor and trainee the trainee must take an active role in their learning, adapting to the supervisor's learning approaches (Brydges et al., 2020). Students can feel that they are not being supervised appropriately for their level of knowledge and training or having variable teaching experiences with some experiencing inhospitable supervision (Girin et al., 2021).

Students with high levels of stress and low self-esteem due to low levels of emotional intelligence and social skills and unfamiliarity with the specialised environment are unlikely to have a flourishing relationship with their clinical supervisors and effective learning will not occur (Dungay and Yielder, 2017; Olmos-Vega et al., 2018; Sa et al., 2019; Girin et al., 2021). Students' wellbeing can be reduced in response to negative situations in challenging clinical environment leading to negative emotional responses manifesting as anger, anxiety, reduced motivation, and irritability which impedes the formation of successful supervisor trainee partnerships (Girin et al., 2021). Dungay and Yielder (2017) feel that the medical imaging radiographers referred to in their study had close to homogeneous predominant preference combinations well suited to the professional and there may be a trend towards showing a personality and learning pattern associated with the profession. There may be deficits affecting clinical dynamics when radiographers are stressed, anxious or fatigued and this may be amplified in the supervisor/trainee relationship leading to an unfavourable learning environment (Dungay and Yielder, 2076).

Olmos-Vega et al. (2018) and Horsburgh and Ippolito (2018) have a particular interest in the successful supervisor/trainee relationship using constructivist grounded theory and qualitative interpretative methodology respectively, recruiting medical students, residents, and clinical tutors as participants. Horsburgh and Ippolito (2018) feel that as a first step it is essential that students participate in 'legitimate peripheral participation', meaning that they need to be invited to participate in a meaningful task related to their practice creating a valued learning experience. Observing role modelling is a good way of learning in the clinical environment but it is a slow, continuous process so students should be paired with supervisors for a set amount of time, but this is challenging in a busy workplace (Horsburgh and Ippolito, 2018). A supervisor and trainee need to adapt to each other's preferences on what to do and how to do it to develop a shared understanding (Olmos-Vega et al., 2018). The teachers interviewed in Horsburgh and Ippolito's (2018) study felt that clinical placements had a fragmented nature, so trainees were not constantly supervised by the same person creating difficulties forming a learning partnership and understanding each other's preferences. The supervisors in Olmos-Vega et al.'s (2018) study expressed how it took time to find commonalities with their trainees, the adaptation to work with each other was a continuous and bidirectional process developing over time. For the trainee, the adaption process consisted of: "complying with the supervisor's directions, negotiating supervisor's preferences leading to shared decision making," in a continuous loop (Olmos-Vega et al.2018 p.732). This model does not account for stressed or anxious students who are unable to conform or students with constant changes in supervisors (Dungay and Yielder, 2017; Girin et al., 2021).

6.4 Conclusion

The literature has revealed that clinical departments are busy, erratic complex environments caring for patients, some who are extremely unwell and or vulnerable. There are intricate relationships and interactions between staff and patients. There are many emotional-psychosocial factors effecting radiographers pre- and post-registration as they learn in the clinical environment. The changeable nature of the clinical department can influence trainees' well-being. Students are coping with the development of themselves as well as the ability to control their emotions. A high level of emotional intelligence and critical thinking is required to participate and learn in the clinical environment but sometimes students do not have a high level and suffer low self-esteem and stress which affects their learning.

Relationships are complicated in the clinical environment and in an ideal world a trainee would be assigned to a supervisor for a large period of time so they can adapt to each other and develop a shared understanding. Trainees rarely have the opportunity to have a consistent supervisor. Role modelling plays an important part for trainees to learn clinical skills and behaviours, the articles reviewed felt that role modelling was a positive successful way of learning. Learning and personal preferences can differ, and they can make it difficult for trainees and supervisors to adapt with each other.

Learning in clinical placements can be rewarding or can lead to reduced motivation depending on psychosocial factors. It is important for qualified staff and academic institutions to recognise the effect of psychosocial factors in the clinical environment.

Chapter 7- Longitudinal study- Part 1

7.1 Introduction

The longitudinal study is the second part of this mixed-method study. The convergence analysis of the first phase, the cross-sectional survey, identified trends and relationships which were used to shape the longitudinal phase of this study (Cresswell, 2015).

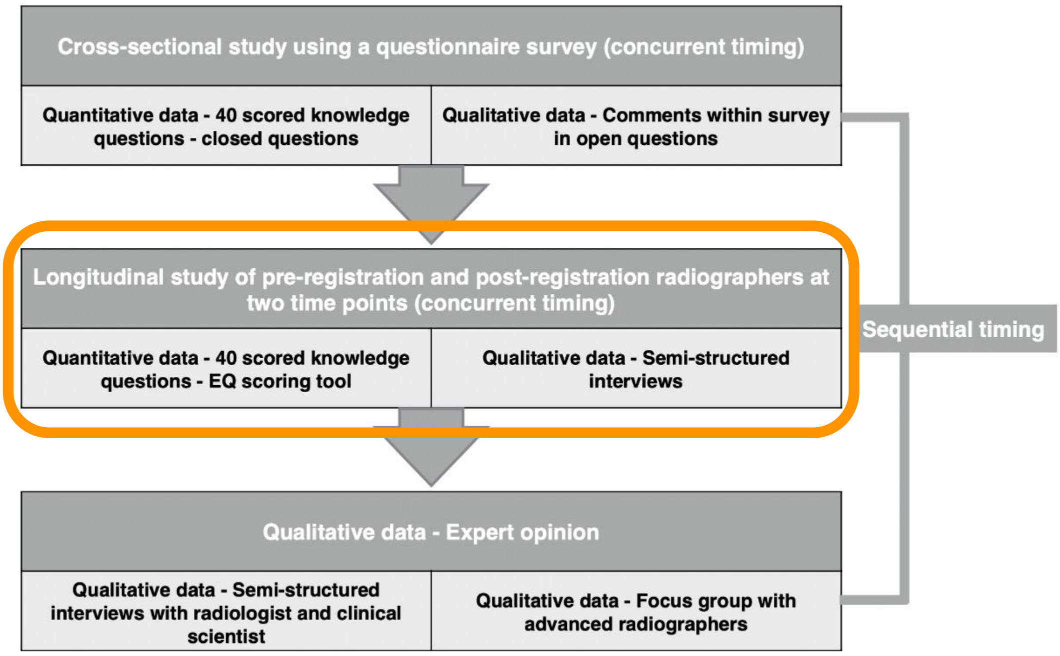

Figure *7.1 Schematic diagram of the research design- phase2-Longitudinal study*

The aim of this phase of the study was to identify training requirements for UK CT radiographers, and to discover whether social/educational factors in the clinical environment have a bearing on the students' approach toward CT dose optimisation, pre-and post-registration. The objectives of the of the longitudinal study was to: a) explore student radiographer's knowledge and experience of dose optimisation within CT scanning; b) measure their emotional intelligence; and c) explore their educational experience. This chapter follows the first part of the journey of a final year student radiographer (part 1) to their first post (part 2) capturing the change in perception of training requirements, and their knowledge of CT dose optimisation. The transition from student to qualified radiographer can be a difficult time in CT scanning. Naylor et al. (2015) explain that students are familiar with the clinical department due to their undergraduate placements, students can only work in CT fully supervised as supernumerary observers and are then expected to work unsupervised after graduation. This phase of the study builds on the previous phase of the cross-sectional survey investigating the same subject matter in detail via in-depth interviews with questions formulated from the topics identified in the survey.

7.2 Background

The cross-sectional survey identified five sub-themes in education which were: standardised training at undergraduate level, postgraduate training, on-the-job training, CT focused Continuous Professional Development (CPD) or manufacturer's training. Qualified radiographers in the cross-sectional study felt that knowledge of dose optimisation varied greatly and that most of the learning occurred in the department from colleagues as these comments suggest:

"As CT is often learned "on-the-job" you tend to learn what the person teaching you knows - this person often does not have a full appreciation of the fundamentals of CT."
"It seems the great majority of radiographers learn CT on-the-job rather than in an educational organisation. These radiographers are capable of performing the scans but some of them above 70% don't know how technical parameters may affect dose and image quality."

Smith-Bindman (2019) concluded that the variation in CT doses across countries were primarily attributable to local choices regarding technical parameters, 98% of radiographers in the cross-sectional study felt that further education within optimisation of CT parameters would be beneficial. One radiographer felt that:

"*Understanding the radiation issues behind CT protocols is key to the CT radiographers role. Who else would do this vital job?*"

It is hard for pre-registration radiographer to acquire enough skills and knowledge in the clinical environment to meet the Health and Care Professions Council's (HCPC) requirement for non-contrast CT head scans, when some of the supervising radiographers lack key knowledge on exposure parameters (HCPC, 2013). Pre-registration radiographers are expected to navigate the clinical setting, whilst learning skills from radiographers who feel they lack contemporary knowledge. There are several influencing factors in the clinical learning environment and pre-registration radiographers are expected to apply current knowledge and skills learnt in their education establishment as well as applying psychosocial skills in their everyday interactions (Arkan et al., 2018; Pitkänen et al., 2018).

In an increasingly busy demanding clinical environment, healthcare professionals in training can be emotionally challenged and are required to manage their emotions. These emotions include feelings of uncertainty relating to: patient interactions, limited knowledge and skills, position in the team, and the culture of healthcare professionals they are working with, they are required to learn emotional confidence during their training to become a competent healthcare professionals (Weurlanderet al., 2019; McCloughen et al., 2020). Understanding social intelligence has advanced due to developments in neuroscience; the brain is wired to connect with others using interpersonal skills (Goleman, 2007). CT radiographers working in close teams during long shifts will influence each other emotionally, and emotional intelligence (EI) contributes to providing patient-centered care (Mackay et al., 2021). Emotional intelligence is a trait specific to an individual, but it can be influenced by short-lived moments of contact with other people (Golemen, 2011). Emotional intelligence that includes self-control, motivation, enthusiasm, and determination can be taught and modified throughout life (Golemen, 2011). Emotional intelligence is important in social organisation psychology and can predict outcomes in the workplace/ clinical environment (Dåderman and Kajonius, 2022). It is likely that during the transition from student to qualified radiographer EI will change.

From reading the systematic reviews in this work, it is evident that very little has been published on radiography specific influences in the clinical learning environment, and none with a holistic multi-factorial approach to exploring the factors that influence learning in the clinical imaging environment. The longitudinal study sets out to explore how radiographers change over time from pre-registration to post-registration in their approach to CT dose optimisation and how factors in the clinical environment, both social and educational, change their perception of CT dose optimisation. The depth of a mixed method study aims to identify training needs for pre- and post-registration radiographers.

This chapter will describe the findings of the first part of this longitudinal study and the findings of the second part will be discussed in the next chapter. Emotional intelligence findings will be discussed in chapter nine.

7.3 Methods

The qualitative data from the cross-sectional study discussed in the previous chapter, lacked depth and was a record of a person's view at that point in time, which is a common limitation of survey data (Hammarberg et al., 2016). The survey showed a lack of real educational data to give sufficient background to CT dose optimisation.

The longitudinal study was considered best way to look at the chronological development and mutual/ social learning within CT dose optimisation. The longitudinal study will add to the knowledge gained from the cross-sectional study acting as an alternative source of data, complying with best practice using both cross-sectional and longitudinal designs in the same study (Spector, 2019).

The first time point of the longitudinal study was an invitation to a cohort of 130 final year students enrolled on a BSc Diagnostic Radiography and Imaging course. Twenty students expressed an interest to participate and fourteen were interviewed. Themes identified in the cross-sectional study have contributed to the formation of the interview questions in the longitudinal study. Qualitative data, collected in parallel at two discrete timepoints, was dominant in the longitudinal study as opposed to the quantitative data in the cross-sectional survey (Brannen, 2005; Cresswell, 2015).

The qualitative data in the longitudinal study is gained via in-depth face to face interviews to provide breadth and depth of data. This part of the mixed method study is 'fully longitudinal' since it collects quantitative and qualitative data at both time points, taking it from a basic to a complex mixed method study design (Van Ness et al., 2011; Plano Clark et al., 2014,). Longitudinal study methodology is suited to phenomena that change over time, so an appropriate way to investigate students on the verge of their career in radiography (Plano Clark et al., 2014). Aspects identified in student transition by Bellizzi et al. (2018) such as a theory-practice gap can be explored with a longitudinal method.

As well as the face to face interviews an emotional intelligence (EI) questionnaire (TEIQue-SF tool (Appendix 2)) and a pre-validated questionnaire on CT parameters (Appendix 1) were completed at each time point (Petrides, 2009; Foley et al., 2013). The TEIQue-SF is a widely used validated emotional intelligence tool and this short form consists of 30 questions to measure global intelligence, producing four sub scales of well-being, self-control, emotionality and sociability (Petrides, 2009; Dåderman, and Kajonius, 2022). Interpretative Phenomenological Analysis (IPA) was used to formulate the interview questions, the structure and the nature of the interview questions was informed by consideration of the principles of IPA (Eatough & Smith, 2008). IPA allows the interview questions to be broadly constructed, which enhances data collection and allows unexpected themes to develop.

This longitudinal study is a mixed methods approach using convergent parallel methods, integrating, and connecting quantitative and qualitative data which were acquired simultaneously on two separate occasions.

The second time point is described in the next chapter with same data collection method.

Ethics

The application for ethics for this longitudinal study was approved by the University of Hertfordshire Ethics Committee with Delegated Authority HSK/UH/02331 from 11/03/2016 until 01/06/2017 this was later extended until 01/06/2018 (aHSK/UH/02331). The extension was required because the longitudinal study involved interviewing final year undergraduate radiography students and then re-interviewing them when these have spent a year in CT scanning in their first post as radiographers. Some of the student radiographers did not get jobs straight after qualifying and some did not get rostered into CT scanning as newly qualified radiographers, so more time was needed to capture their experiences of CT scanning.

Consent

The students were given a participant information sheet and a consent form. They were given time to decide if they wished to participate in the study. They were able to withdraw from the study at any time point since the data collected at the original time point had a specific identifier known only to the researcher and was kept on a password protected file in a password protected computer.

Quantitative and qualitative data was obtained. The qualitative data via face-to-face interviews which were analysed via thematic analysis. The quantitative data came from the 40 CT parameter questions on dose optimisation and the EI TEIQue-SF tool (Petrides, 2009; Foley et al., 2013). Synthesis of the data investigates whether any associations exist between the data sets.

Results were analysed via descriptive statistics, EI scoring and thematic analysis. Mean scores of the group were compared with the cross-sectional survey, which were analysed using the same method. Open-ended interview questions providing qualitative data were coded and trends emerged which identified the main themes.

The main advantage of this study is that the subjects are completely matched, and they become their own control group. A disadvantage is that participants can become familiar with the questionnaires since they have completed them twice or they may become bored with answering them. There were however only two time points on the study. The questionnaires were validated through publication and use, the disadvantage being that students could have looked up the answers. There was no evidence of this or that they remembered their answers from two years previously.

The repeated measure design is powerful since it culminates in a matched statistical analysis. The number of participants in this study was low but this is accounted for in the degrees of freedom on the significance table. The results for the group were compared, not individual scores.

7.4 Findings

7.4.1 Quantitative data

This longitudinal study included 14 pre-registration radiographers, with a mean age of 26 with a range of 21 to 50 years old. 21% were male and 79% were female reflecting the gender makeup of the pre-registration cohort. Three had previous degrees.

Profession	*n*	Mean	SD	Min	Max
UK radiographers	47	29	3.7	23	36
Pre-registration	14	24	4.5	16	31

Protocol and parameter questions

Table 7.1 - Comparison scores between UK radiographers and pre-registration radiographers

The Kolmogorov-Smirnov Test of Normality was carried out on each set of data. The result of the test for normality revealed that the data does not differ significantly from a normal distribution thus parametric tests could be performed on the data (Samuels and Marshall, 2013).

A t-test for independent means was carried out. The hypothesis being that there was no significant difference between the groups. A two-tailed test was used since the distribution was symmetrical (*t* distribution): the test was for positive or negative differences in the two groups. When the 47 participants in the UK radiographer group (M= 28.55 SD= 3.7) were compared to the 14 participants in the student pre-registration group (M= 23.64 SD= 4.5) demonstrated a significantly higher score $t(59) = 4$, $p=0.000122$.

Cohen's *d* effect calculation ((23.64 - 28.55) ⁄ 4.119466 = 1.191902.) = 1.2 indicating that the two groups differ by 1.2 standard deviations, giving a very large effect size above 0.8. (Cohen, 1992). Cohen's *d* requires similar standard deviations. When these results are put through a G*Power 3.1 calculator, power was calculated as .97 which is greater than the desired power of .80 indicating the sample size was large enough (Faul et al., 2009; Stangroom, 2021).

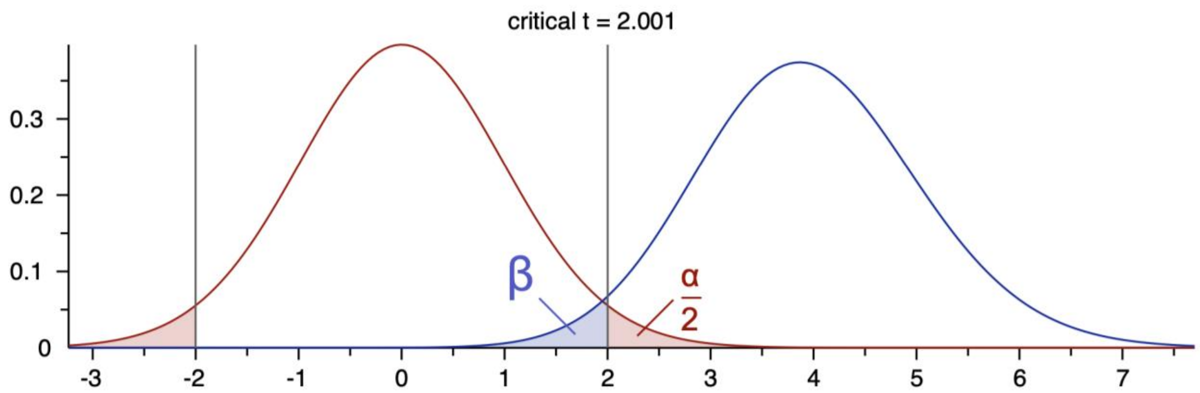

*Figure 7.2 - G*Power calculation from data from the two groups* (Faul et al., 2009)

These were the expected results because students were being compared to qualified members of staff who have had an undergraduate degree or equivalent as well as experience in CT scanning.

7.4.2 Qualitative data

The qualitative data were obtained at the same time as the quantitative data, both approaches in parallel. The in-depth interviews provided qualitative data and made qualitative data dominant in this part of the study. The in-depth interviews were recorded, and contemporaneous notes were made. Analysis of qualitative data was prepared in a systematic and rigorous manner, matching the methodology used in the cross-sectional survey with thematic analysis following the Braun and Clarke (2021) qualitative data analysis framework was used to produce these findings (Pope et al., 2000).

Three themes were identified:

1. Education
2. Dose optimisation
3. Culture

Education

Students were asked what type of education was desirable to work in CT scanning. Students reflected on their undergraduate training as well as training they would undertake in the future to achieve dose optimisation in CT scanning. At the time of the first interviews the participants had completed their academic training and were expressing their aspirations for the training they felt would be useful as qualified radiographers. Their opinions may change post-registration, and this is explored in the next chapter.

Education results

Table 7.2 - *Frequency table - education- longitudinal study -part 1*

Sub-category	Number*
On-the-job training (including radiographer & radiologist talks/training)	20
Applications training/talks	8
Study days	2
Undergraduate training	7
Post Graduate training	7

*Numbers are individual mentions.

The analysis of the data from the participant interviews showed five sub-themes:

1. Undergraduate training
2. Postgraduate training
3. On-the-job training (including radiographer & radiologist talks/training)
4. Applications training/talks
5. Study days

Undergraduate Education

At this first point the student radiographers felt that basic CT physics and positioning had been covered at undergraduate level, but they were aware that their knowledge may become outdated by the time they started working in CT. Students thought this was likely to occur a year to eighteen months after their training. Some students felt that a CT scanner or virtual CT scanner should have been available to them on their course so they could have learnt the basic skills and how the CT worked before attending the clinical environment. Gunn et al. (2021) investigated student's perceived confidence when virtual reality CT (VR CT) was used at undergraduate level and concluded that VR CT improved students' preparation for the clinical environment giving them confidence via the integrated learning. Gregory et al. (2015) consulted 200 educators and even though VR systems had failed at their institutions due to ownership of the VR system, they felt that they were important to motivate and engage learners as well as allowing learners to become familiar with the systems and allowing students to make mistakes without any negative consequences (Gunn et al., 2021).

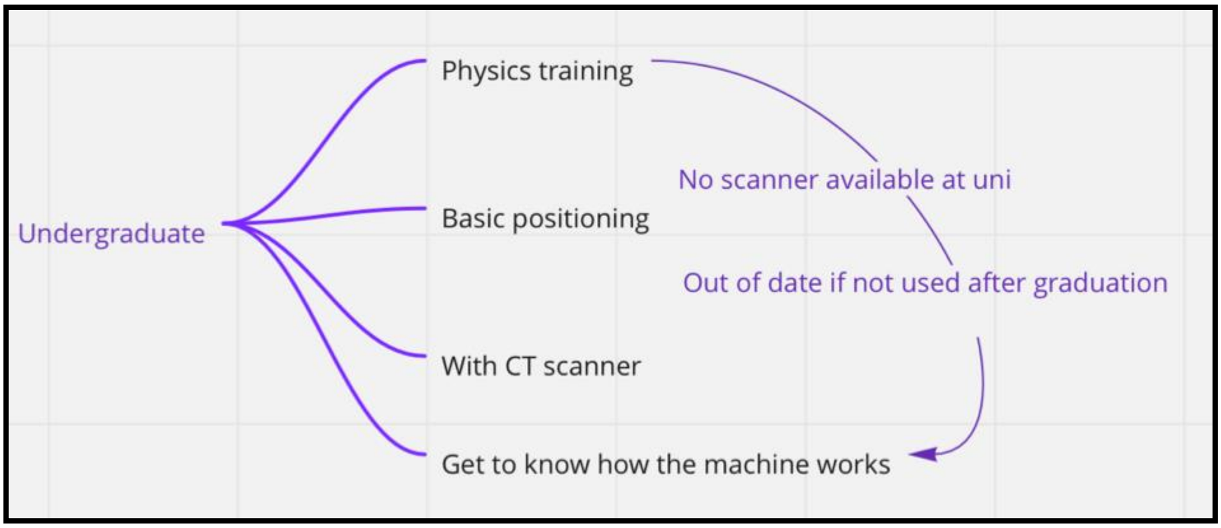

Figure 7.3 - *Mind map for undergraduate education sub-theme*

Table 7.3 - *Pre-registration radiographers' comments*

"I think we already have the physics knowledge under our belt" UG12
"Training that you are not doing straight away would probably be out of date by the time you get to do it" UG14

Postgraduate Education

The participants felt that funding could be a problem for a postgraduate CT course. Most departments would expect staff to gain a postgraduate qualification in ultrasound (US) and magnetic resonance imaging (MRI) but since CT head scanning is a core competence in the HCPC professional standards it is rarer for CT radiographers to be funded for a postgraduate CT course (HCPC, 2013). Even where a student self-funds there is an economic impact of replacing staff to attend courses. This concurs with Sloane and Miller (2017) report that postgraduate education in CT was an exception. Cross-sectional imaging is complex and the lack of education at postgraduate level is a problem, as per the respondents in Sloane and Miller (2017) cross-sectional survey, who felt that radiographers without a sound knowledge of CT were teaching less experienced radiographers.

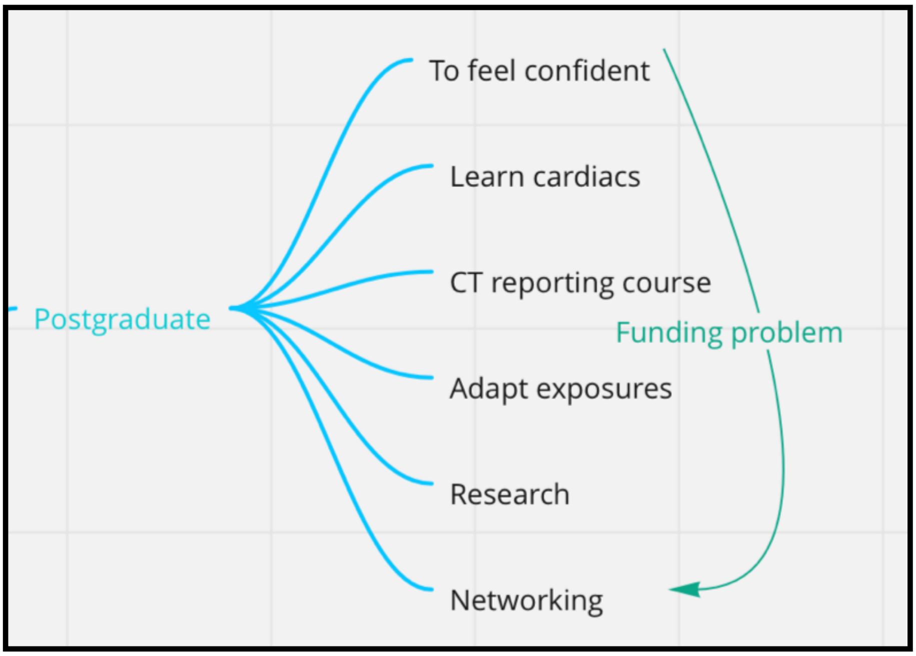

Figure *7.4 - Mind map for postgraduate education sub-theme*

The pre-registration radiographers felt that postgraduate education would be useful for role development such as reporting CT scans and CT cardiac scanning. They acknowledged that postgraduate education would help with the theory-practice-gap via research informed teaching and provide tools for continuous professional education and networking skills (Higgins et al., 2017).

Table 7.4 - *Pre-registration radiographers' comments*

"Formal post grad CT, to be able to do Cardiacs" UG4
"………. depends on department money and whether they think it is worthwhile" UG10

On-the-job training

This sub-theme attracted the most comments. Participants were very keen to draw on the expert knowledge available in the department from senior staff and radiologists. The students acknowledged that CT scanning was a complex, fast-paced modality and that practical training was best carried out in the department. On-the-job training included practical training such mentorship by senior staff and gaining of competencies which gave students confidence. They felt that one-to-one training was the best way to learn and understand local protocols and use different types of CT scanners. There were no negative comments about on-the job training and there were no expressions of concern about time or resources for the training. One of the reasons on-the -job training can be sub optimum is that there is an assumption that if healthcare professionals are experts in their field that they can teach, but for effective clinical teaching expertise alone is not sufficient and formal training is required (Spencer, 2010). Another reason is that in a busy department, radiographers who have participated in formal training, are forced to give brief and often less optimum teaching (King et al., 2020).

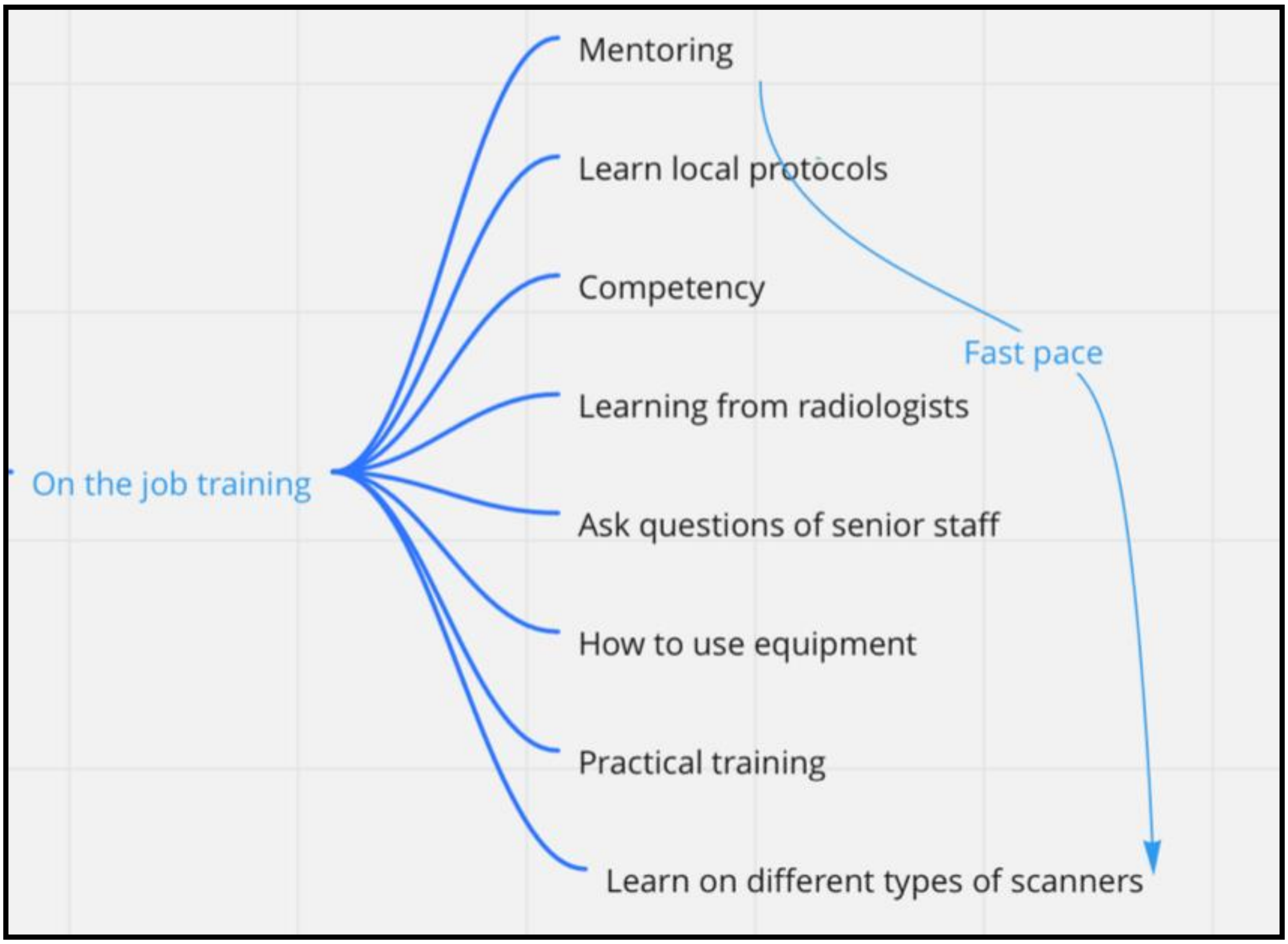

Figure *7.5 - Mind map for on-the-job training sub-theme*

Table 7.5 - *Pre-registration radiographers' comments*

"Like some monitoring of first weeks to make sure I'm doing it right." *UG3*
"…following senior people, getting advice, watching what they do" *UG7*
"Sitting with the radiologist and learning" *UG4*
"I would want on the job training. When I have been doing CTPAs I have been doing CTPAs I have been learning everything on placement" *UG2*
"I know at my site it has booklets which they go through all the competencies, all the training required to ensure that everybody is completely confident and competent in in CT" UG14

Applications training

Students felt that applications training would provide learning at a slower pace than in the clinical environment and that they would benefit from knowledge of new techniques and new systems. They felt it would enable them to use the scanner more efficiently since the trainers would be experts in the scanner's hardware and software and they may not be able to optimise dose with just on-the-job training. Students and junior staff are not normally present when initial application training occurs for new scanners or after major software or hardware updates. Applications knowledge is usually cascaded through the department via senior staff so students and junior staff would only have exposure to applications training if they attended user group meetings. Although the majority of the pre-registration radiographers felt that on-the-job training was best for their education, they seemed to think that they required applications training for software and hardware applications, to change parameters for different patient types and because the radiographers teaching were not explaining how and why parameters were set indicating the on-the-job training was not the most effective training method.

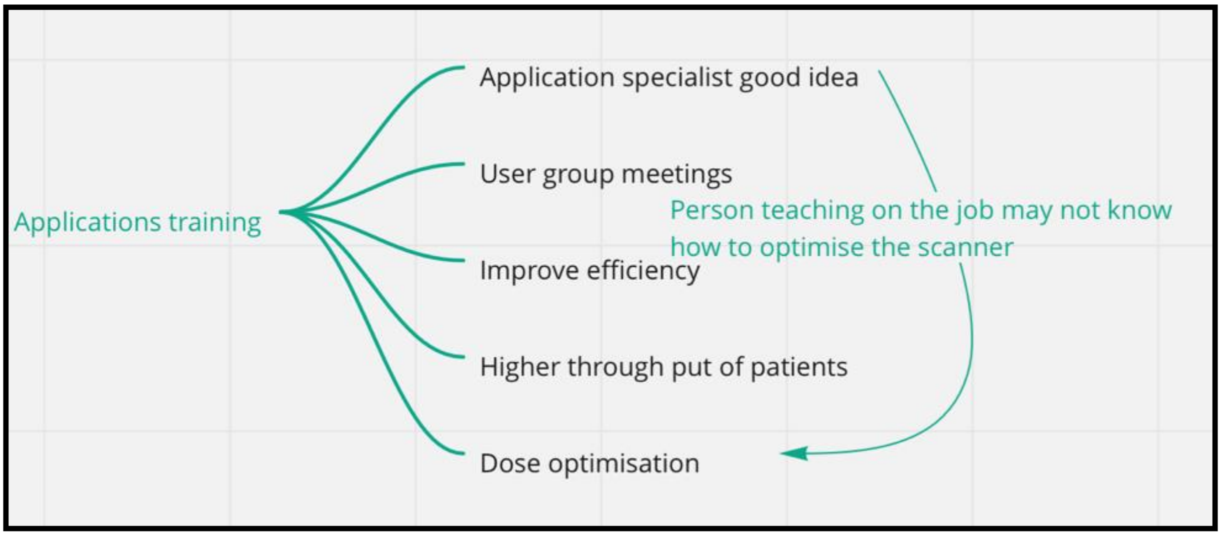

Figure *7.6- Mind map for applications training sub-theme*

Table 7.6 - *Pre-registration radiographers' comments*

"Applications specialist, I think it would be a good idea" *UG9*
"..… improve efficiency of the use of the scanner" *UG14*
"…. the technical and hardware and software applications" *UG12*
"Applications because they don't show how to use, just click on this and click on that not really explaining it." *UG5*
"…if you get stuck doing one thing one way you think it is the only way to do this thing" *UG14*
"…. I feel the practical side not enough" *UG7*

Study days

Only two comments were made about study days. One comment was incredibly in favour of study days. One participant thought that in-house study days would be best when the department was quiet, giving the radiographers time for their training. They thought the benefits would be networking with people who have similar scanners and finding out how other Centres function. They felt that the practical side of scanning was not enough.

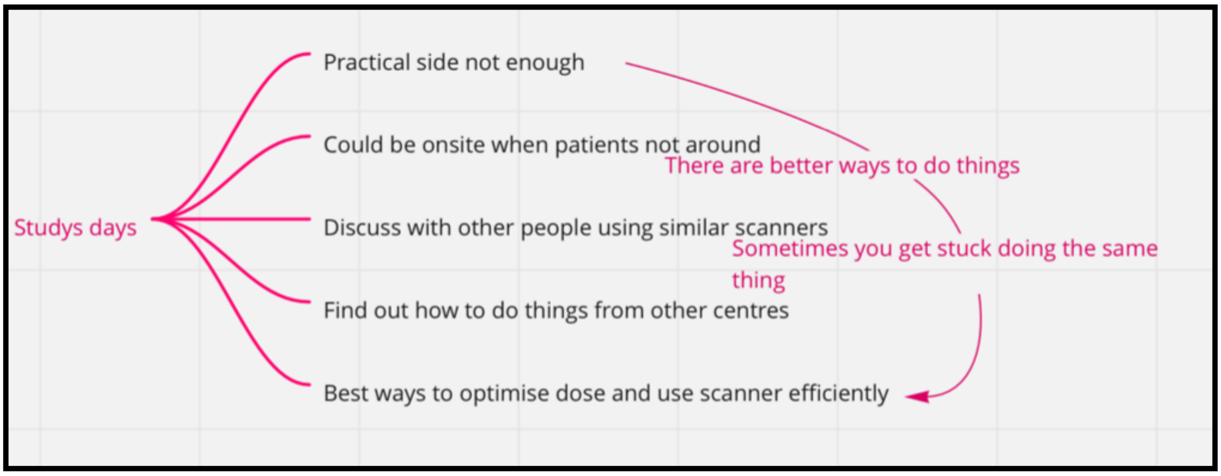

Figure *7.7- Mind map for study days - sub-themes*

Table 7.7 - *Pre-registration radiographers' comments*

"........talking to other people who use similar scanners" *UG14*
"I love learning so I feel the practical side not enough. Thought on study day when patients are not around, could be onsite." *UG7*
"would also be useful for learning the best ways to use the scanner efficiently and as dose optimisation methods because at the end of the day if you get stuck doing one thing one way and you think it is the only way to do this thing " *UG14*

Dose optimisation and collaborative working

Table 7.8 - *Frequency table*

Sub-category	Number*
Field of View (FOV)	14
Exposure parameters not adjusted	7
Reduce exposure	23
Collaborative working	8
Justify exposure	3

*Numbers are individual mentions.

Dose optimisation results

The analysis of the data from the participant interviews showed five sub-themes:

1. Field of view
2. Exposure parameters not adjusted
3. Reducing exposure
4. Justifying exposure
5. Collaborative working

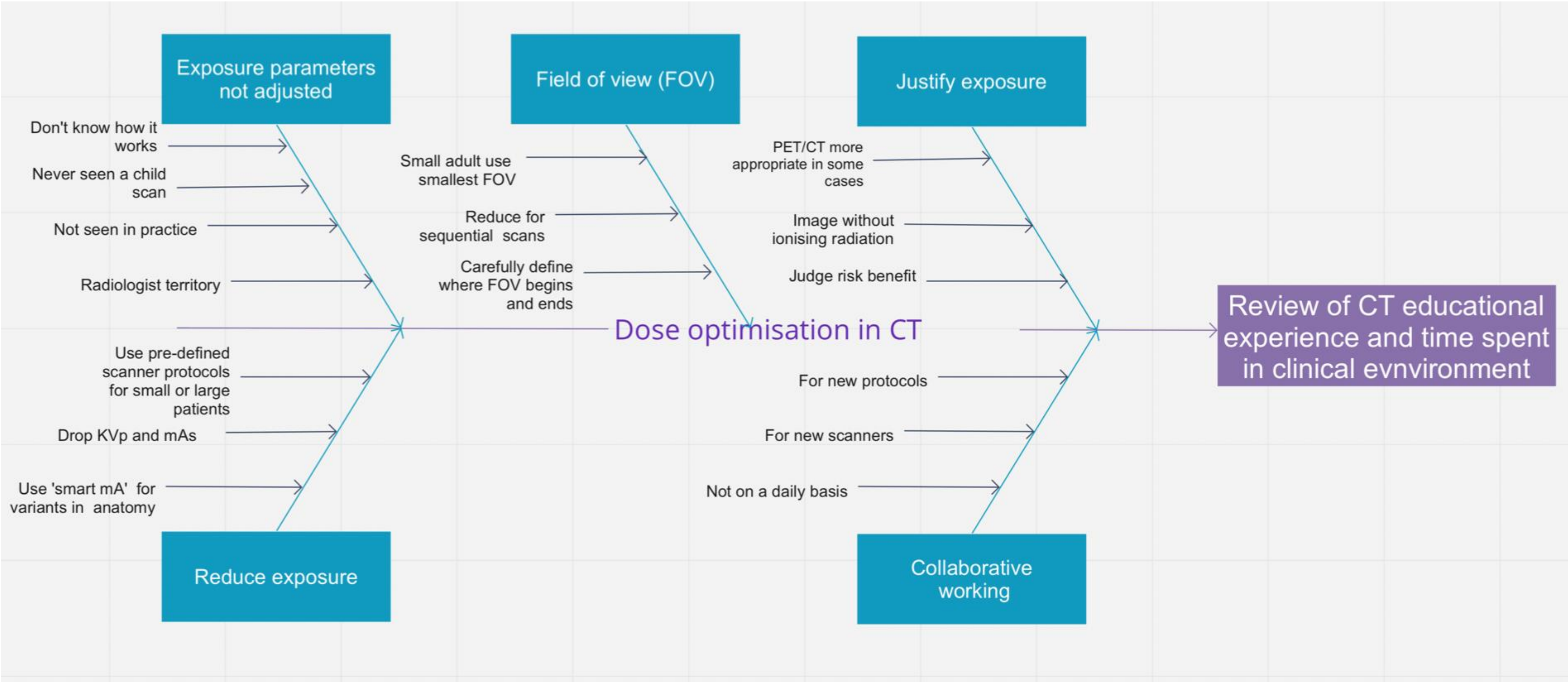

Figure *7.8 - Fish diagram for dose optimisation*

Field of view (FOV)

The selected CT scan length is important because it needs to include the relevant anatomy detailed in the clinical request. An increased scan length (FOV) will result in an unnecessary increased radiation dose to the patient as well as having the potential to reduce the image quality from artefacts within the FOV and image noise (Ebrahimian et al.,2021). Ghoshal and Gaikstas (2021) looked at CT Kidney/ureter/bladder (KUB) scans in clinical practice and concluded that 89.8% of CT KUBs performed in their study over-scanned the target level of the upper pole of the highest kidney which increased the total radiation dose to the patient. The worst-case scenario showed an over scan of 50 mm causing a radiation dose four times the expected level of 200 mGy/cm, although this was not a linear relationship and they also had three outliers with an over scan of over 80 mm that did not increase the radiation dose to the patient. Uldin et al. (2020) revealed that an over scan above 15% occurred in 94.4% of their audited scans and they concluded that this was due to lack of clear scanning protocols, after changing their protocol with clearly defined scanning levels supported by clearly illustrated images, they managed to reduce the DLP for KUBs by 149%.

Selecting the optimum FOV for each individual patient is a simple way for the operator to reduce radiation dose to an individual patient, clear guidance in the form of protocols can aid the radiographer and indicate that the department expects precise scanning for the benefit of patients and the overall radiation dose to the environment. Reducing the FOV in CT is associated with higher spatial resolution and therefore reducing it has benefits for radiation dose and image quality (Miyata et al., 2020). Kim et al. (2010) advocate that in clinical practice a larger FOV may be helpful, they found that 89% of early lung cancers were missed in their cardiac CT study because of a limited FOV was used. Clear departmental protocols and discussion with referrers can help radiographers select the desired FOV.

Some participants felt that radiographers were not using protocol driven scanning techniques or precision scanning but more just getting on with it and ploughing through patients in busy departments.

Table 7.9 - *Pre-registration radiographers' comments*

"I don't think that (this is) the expected norm of radiographers" *UG12*

Refreshingly students found that some departments seemed to be more aware of procedures and protocols.

Table 7.10 - *Pre-registration radiographers' comments*

"You have got to be optimising the procedures and the protocols for patients having repeat scans ensuring that you do not scan unnecessary areas" *UG14*
"Try and identify where liver starts and ends on pre-scan and make sure you get correct FOV on other scans." *UG6*

A student's perception of protocols and procedures within the CT scanning department may not be a true reflection of the actual situation and part 2 of the longitudinal study will more accurately measure this.

Exposure parameters not adjusted

Hyde (2015) found that support from clinical staff during clinical placements can vary, concurring with previous studies. In CT with an extremely busy workload, including very ill patients, and advanced technology. Students find it difficult to integrate with the busy team which has an impact on learning. Large Trusts with more than one site can choose to train junior undergraduates in their non-acute hospital where all the patients are outpatients which means that the students will have greater access to the team and have more time to scan patients. Once students had gained their competencies, they then had placements in the extremely busy CT department in the acute Trust, this worked very well but all clinical sites cannot accommodate this. England et al. (2017) acknowledge that supervision of students in clinical practice is essential, the advantage of CT scanning is that full supervision is given to students. The drawback is that not all universities have a CT scanner or virtual learning environment, so students can learn the basics of CT before starting their clinical placement. Sloane and Miller (2017) interviewed radiology managers and found that the diversification in the role of the radiographer coupled with the technical advances of cross-sectional imaging, produced graduates of varied experience and practical usefulness. Participants in the Sloane and Miller (2017) study felt that newly qualified radiographers had difficulties in maintaining parallel competencies in all the modalities they were expected to work in. Several students expressed a lack of clinical experience causing them to be hesitant working in CT. They were unlikely to adjust exposure factors when allowed to work autonomously after qualification due to lack of experience, competency and confidence even thought they were aware of the theory.

Table 7.11 - *Pre-registration radiographers' comments*

"*Never seen a child scanned" UG8*
"Change the kV and mAs changes by itself. You put in dose you want to start on, it then regulates itself. I don't know how it works!" *UG4*
"Not seen in practice" *UG13*
"Not sure in this hospital can choose parameters for children and different body sizes" *UG5*

The feelings of the pre-registration radiographers may change over time. The next chapter will report the findings of the post-registration radiographers.

Reducing exposure

If exposure parameters are not adjusted for the body habitus of the patient, then patients may not receive optimum dose reduction for imaging. Most CT scanners have automatic dose modulation which changes the amount of radiation (mAs) penetrating the patient depending on the physiological makeup of the patient i.e., lungs would attenuate less radiation than the abdomen, so the thorax would have less dose than the abdomen.

Operators tend to use increased radiation exposures to create images with low noise levels, but CT images are created from attenuation maps so there is no direct indication of patient overexposure although the DLP and CTDI are a guide to exposure. Post-acquisition image reconstruction can reduce the level of image noise while maintaining low dose (Gervaise et al., 2012). Zarb et al. (2011) concluded that image quality is detrimentally affected by dose reduction thus effective dose optimisation limits need to be set. The participants were aware of the adjustments that needed to be made for small or large patients but may not know how to achieve this in practice. Some departments have set exposure parameters for smaller or larger patients:

Table 7.12- *Pre-registration radiographers' comments*

"We have different settings on our machine, so for smaller patients you choose the anorexic patient protocol." *UG9*
"So, what I see is radiographers choosing different(programmed) parameters not changing manually" *UG5*

Programming different parameters into the scanner is the best way forward to achieve dose optimisation since it avoids radiographers making errors when adjusting parameters, that could lead to an overexposure of the patient without them realising (CQC, 2012). Having a set of parameters allows for collaborative working between radiographers, radiologists, clinical scientists, and application specialists to achieve the optimum radiation dose to the patient and image quality. Foley et al. (2013) discovered that the influence of some parameters is not well understood by radiographers and radiologists, so individually setting exposure parameters on the CT scanner is not ideal.

Table 7.13- *Pre-registration radiographers' comments*

"I wouldn't turn off the AEC and try with my own mAs plotting" *UG12*
"I wouldn't adjust the kVp" *UG12*
"…….five year old go onto kV and reduce to 60kV" *UG2*
"Bigger body size increase exposure factors" *UG1*

Justifying exposure

Justifying the exposure to be given to an individual patient is part of the overarching radiation protection principles: justification, optimisation and dose limitation derived from the International Commission on Radiological Protection (ICRP) (Valentin, 2007). The principle of justification says that the radiation exposure to the patient should do more good than harm (Moores, 2016). The ionising radiation dose to the patient can be eliminated by using non-ionising radiation such as MRI or US, and this is the task of the IR(ME)R practitioner in UK radiation law (The Ionising Radiation (Medical Exposure) Regulations 2017) [1322].

Table 7.14- *Pre-registration radiographers' comments*

"Judge risk and benefit" UG4
"…. I would discuss with the doctor if there was any new information" UG8
"…you can monitor it using other imaging that doesn't use radiation" UG4

Interestingly one participant suggested that justification might lead to an increased radiation dose to the patient, this is acceptable if the modality with the higher radiation is more appropriate for the individual patient. The participant pointed out that the CT component of the PET/CT scan was less radiation dose than a diagnostic CT. Performing a lower radiation dose scan which is inappropriate would be an unnecessary radiation dose to the patient and therefore not justified.

Table 7.15- *Pre-registration radiographers' comments*

"When CT used with PET/CT, yes lesser dose" UG4

Collaborative working

Chell (2016) in the response to the Committee on Medical Aspects of Radiation in the Environment (COMARE) 16th report, points out that significant dose reduction can occur when scanning protocols are optimised. Chell (2016) states that active promotion and cooperation between professional groups is required to achieve optimisation at a local level. Six of the fourteen participants had not seen collaborative working with radiographers, radiologists, and clinical scientists, being students with limited experience in CT scanning they may not have been aware of the collective teamwork behind scanning parameters. Eight of the participants had seen clinical scientists working with radiographers and radiologists while on clinical placement in CT which is reassuring considering most of the sites were supported by regional clinical scientists as opposed to in-house ones.

Table 7.16- *Pre-registration radiographers' comments*

"…….. for new scanner not on a daily basis" UG2
"MPE, radiologist plus radiographer working together to change protocols" UG13
"For biopsy" UG5
"Change protocols and approval" UG1

Participants in the cross-section survey study were aware of the exact makeup of the multidisciplinary team setting CT protocols and setting up new scanners, and 18% of them included application specialists. The students did not mention application specialists.

Culture

This theme attracted the fewest number of comments with nine recorded. Students described indifference from the qualified team members causing them to assume a passive role. Students in CT always work under supervision from qualified staff so there can be a culture of parent child communication instead of adult to adult as described in transactional analysis (Booth and Manning, 2006).

The analysis of the data from the participant interviews showed four sub-themes:

1. Asking questions
2. Team working
3. Explanation of protocols
4. Passive role

Table 7.17 - *Frequency table - Culture*

Sub-category	Number*
Asking questions	3
Team working	3
Explanation of protocols	5
Passive role	5

*Numbers are individual mentions.

Asking questions

Some students felt awkward asking questions while others felt supported in asking questions. It can be hard to ask questions while working in CT due to the pace of work and complex technical equipment. CT scanning can have a dedicated core team which may not include a student clinical facilitator and therefore students may feel isolated in the modality.

Pitkänen et al. (2018) examined healthcare student's evaluation of their clinical environments and found that third year students were most dissatisfied with their clinical learning environment and supervision in their third year. Sloane and Miller

(2017) discovered that because the role of the radiographer was now so diverse, extensive induction programmes have been introduced in very busy areas such as CT to help radiographers maintain competencies in modalities and because students were not expected to have comprehensive experience in cross-sectional imaging.

Table 7.18- *Pre-registration radiographers' comments*

"Freely ask questions to the senior members and get an answer" UG8
"I should have asked questions when I didn't understand anything. A lot to learn that we haven't been taught. There is a lot that we will, have to learn." UG8

Team working

There was only one comment about team working which acknowledged the need for teamwork in CT scanning. The CT clinical team will be an inter-professional team in most CT departments due to the trauma patients being scanned. Blocker et al. (2013) realised that "technical teamwork problems" were barriers to trauma patient care in the complex and varying modality of CT. Mouser et al. (2018) points out that Inter Professional Education (IPE) at undergraduate level can increase the confidence of student's team working in the clinical environment.

Table 7.19- *Pre-registration radiographers' comments*

"………. communication with staff as well working in a team" UG9

Explanation of protocols

Departments have introduced comprehensive induction programmes for newly qualified staff for CT scanning. Understanding why the protocols have been set is an important knowledge gap the newly qualified radiographers need to rectify. Specific protocols are set for each scanner so this can only be taught in the clinical environment.

Table 7.20- *Pre-registration radiographers' comments*

"Would like to have had protocols explanation of why they change" UG4
"You can do different protocols for different radiologists" UG4

Passive role

Students seem to take on a passive role when they are present in a busy, fast-paced highly complex environment. Students are unable to demand attention from the clinical team so they can be mentored and therefore become more involved. Most CT departments work extended hours and every minute counts when the average scan appointment time is about 5-10 minutes, with most communication and patient preparation occurring outside the scanning room. Lewis et al. (2008) describes radiographers as feeling inferior to radiologists and medical staff as well as being under appreciated so it is understandable that those feelings are transmitted to students, Yielder and Davis (2009) felt that targeted professional development and effective leadership could change this workplace culture.

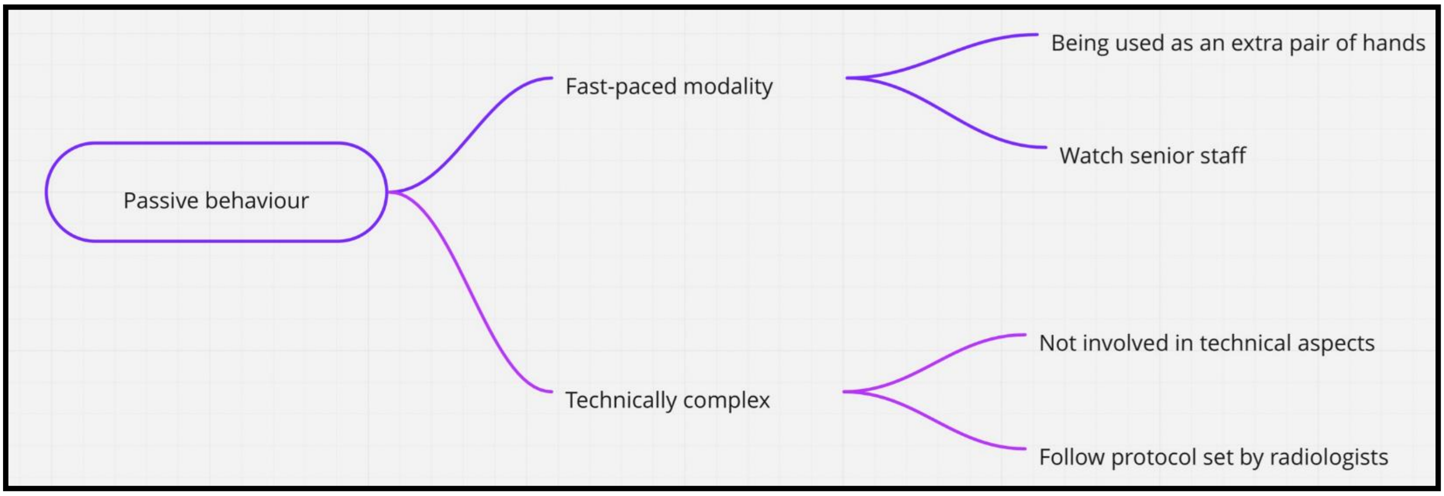

Figure 7.9 - *Mind map for passive behaviour sub-theme*

Table 7.21- *Pre-registration radiographers' comments*

"……. students just helping patients getting on and off table." UG3
"Following senior people, get advice watching what they do, "UG7
"Sometimes we get to press the buttons but not very often, so we don't get involved in those aspects." UG3
"You need to understand why you are doing it." UG7

7.5 Synthesis of quantitative and qualitative results

Peak kilovoltage (kVp)

When answering the questionnaire, only 29% of the participants were aware that increasing the kVp from 120-140 kVp increases CTDI values by 38%, making this the most poorly answered question. Traditionally in CT scanning the tube current (mAs) was adjusted to reduce the radiation dose, but more recently studies have looked at reducing the traditional CT kVp setting of 120 kVp for most patients to optimising the kVp in smaller patients or high contrast studies such as angiographic CT. For the same mAs reducing the kVp can increase image noise but several studies have found that the kVp can be reduced and similar image quality maintained. Reducing kVp reduces radiation exposure to the patient (Joyce et al., 2020, Kim et al., 2009).

A fifth of the students (21%) answering the questionnaire overestimated the increase with 50% knowing that increasing the peak beam energy causes an increase in CTDI values. The other 50% did not even feel that they could guess at an answer.

Interestingly 64% did know that reducing the kVp from 120-100 for CT angiography reduced radiation dose in the next question.

In the 13 qualitative comments about dose reduction, five of the students specifically mentioned reducing kVp for smaller patients (38%). Two participants clearly stated that they would not adjust the kVp in anyway. Most of the students did not understand how this could be achieved in practice due to lack of experience in the clinical environment.

Table 7.22- *Pre-registration radiographers' comments*

""If you have a slim patient take the kV down"." UG2
"I would not adjust the kV" UG12
"Reduce kV to lower amount to keep dose as low as possible" UG8
"if you want to enhance contrast give low dose scan" UG2

This could highlight the lack of postgraduate CT education, mentioned by Sloane and Miller (2017), leading to some radiographers in some Centres teaching knowledge they acquired as a student and not updating their knowledge since qualifying.

Table 7.23- *Comments from the* ***UK radiographers' cross-sectional survey***

"As CT is often learned "on-the-job" you tend to learn what the person teaching you knows - this person often does not have a full appreciation of the fundamentals of CT."
"It seems the great majority of radiographers learn CT on-the-job rather than in an educational organisation. These radiographers are capable of performing the scans but some of them above 70% don't know how technical parameters may affect dose and image quality."

Automated Tube Current Modulation (ATCM) operation

When answering the questionnaire, 86% of the respondents correctly answered that the ATCM is affected by centering of the patient within the gantry matching Foley et al.(2013) findings for their two groups which were 86% and 90%. Overall, the mean score for the question was 64% with a range of 2-4 questions answered correctly out of a total of four. Foley et al. (2013) were most worried by the answer to the question on the use of ATCM with metallic implants with less than half the radiographers and less than a quarter of the radiologists being aware that ATCM can be used with metallic implants. Less than a third (29%) of the students answered this question correctly. In the face-to-face interviews the students showed an understanding of the ATCM, and some mentioned the more advanced tube potential modulation which alters kVp. Winklehner et al. (2011) found that the radiation dose to the patient could be reduced by 25% when using tube potential modulation on a standard 120 kVp setting. None of the students mentioned metallic implants.

Foley et al. (2013) explain that ATCM can reduce radiation dose to the patient by 35-60% but only if the patient is correctly positioned and image quality measured must be set either as noise index or quality reference tube current. The majority of students (85%, 12/14) correctly answered the question saying that ATCM is affected by centering of the patient within the gantry but only four of them mentioned it in the interviews when asked about the ATCM and only two students said that they would repeat the scout/topogram view if they had centered the patient incorrectly. The scout view is a low dose body map which aids the scanner to calculate the current required depending on density of the body if this is setup incorrectly the exposure will not be optimise for the patient's body size and anatomy. The quantitative comments may indicate that some students did not have a complete understanding of the way the ATCM works.

Table 7.24- *Pre-registration radiographers' comments*

"If you don't check you are not really doing your job perhaps" UG14
"...appropriate modulating" UG12

7.6 Conclusion

The students were in the last stages of completing their course and were about to begin their career in diagnostic radiography including CT scanning. The quantitative data showed that their knowledge of CT exposure parameters was less than the qualified UK radiographers and this could be accounted for in the lack of experience in CT scanning. The face-to-face interviews revealed three themes: education, dose optimisation and culture. Collaborative working was included as a sub-theme in the dose optimisation theme. The pre-registration radiographers were aware of the requirements to optimise dose, but some lacked experience to know what to do in practice. With many not ever being allowed to change parameters under direct supervision. This led to a lack of understanding of the dose reduction including reducing the kVp and using the ATCM correctly.

Most of the participants felt that on-the-job training was the best way to receive training and education in CT scanning. The pre-registration radiographers did not express any reservations about on-the-job training although the UK radiographers in the cross-sectional felt that there was a knowledge gap. Students may not have wanted to return to academic training because the students had just attended three full years of academic education and may have a bit of fatigue, it will be interesting to see if their views change after qualification.

The students felt that the careful selection of the FOV could optimise dose and that dose optimisation could be achieved adjusting CT parameters to reduce radiation exposure. This is especially important for children and small patients, although most had not seen this in practice. Some students felt that justification of ionising radiation exposures had a part to play in reducing the radiation dose in CT. Performing an alternative technique especially with non-ionising radiation, may be more appropriate and therefore reduce the patient's ionising radiation exposure.

Some participants mentioned the culture of the clinical placement from a student's perspective. Several students adopted a passive role in the department which had an impact on their training and skill set. The fast paced, highly technical environment of CT scanning meant it was a challenging learning modality as a student. Most departments have acknowledged this and have developed extensive preceptorship programmes for newly qualified staff to enable them to obtain the skill set required for CT scanning. Some students felt supported in CT during their training, while others felt they were being used as an extra helper.

The next chapter will explore the feelings of the participants as they transition from student to qualified member of staff.

7.7 Robustness and external validity of study

Major, V., Ryan, S., O'Leary, D. *Exploring academic and social factors effect on CT dose optimisation- a longitudinal study of radiographers from student to first post.* Oral presentation, Health and Social Work research conference Hatfield 2019

Major, V., Ryan, S., O'Leary, D. *Exploring academic and social factors effect on CT dose optimisation- a longitudinal study of radiographers from student to first post.* Oral presentation, ECR Vienna 2019

7.8 Mapping the content of this chapter to the aim and objectives

The Aim of this study is to identify training requirements for UK CT radiographers regarding specifically social, clinical, and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation. This chapter partially met the aim, since it reviewed the current knowledge of CT parameters and their influence on patient dose and image quality amongst pre-registration radiographers. Training needs were identified in this group of respondents. Social, clinical, and educational factors were considered in this chapter.

This chapter met the following objectives:

- to explore radiographers' knowledge of exposure parameters and view on education
- using a longitudinal study explore pre- and post-registration radiographers' knowledge and experience of dose optimisation within CT scanning
- using a longitudinal study explore the radiographers' educational experience
- using appropriate methods of analysis compare and contrast data with evidence base
- discuss combine and contrast emerging themes
- document the findings accurately and coherently for dissemination.

Chapter 8- Longitudinal study- Part 2

8.1 Introduction

The second part of the longitudinal study investigates the transition from student to qualified radiographer to explore the feelings and perceptions of the newly qualified radiographers as they transition to working in more complex modalities and how these impact on their opinions of dose optimisation. In-depth interviews were used to acquire qualitative data. Quantitative data was obtained from a validated trait emotional intelligence questionnaire (TEIQue) and CT parameter scores from Foley et al. (2013).

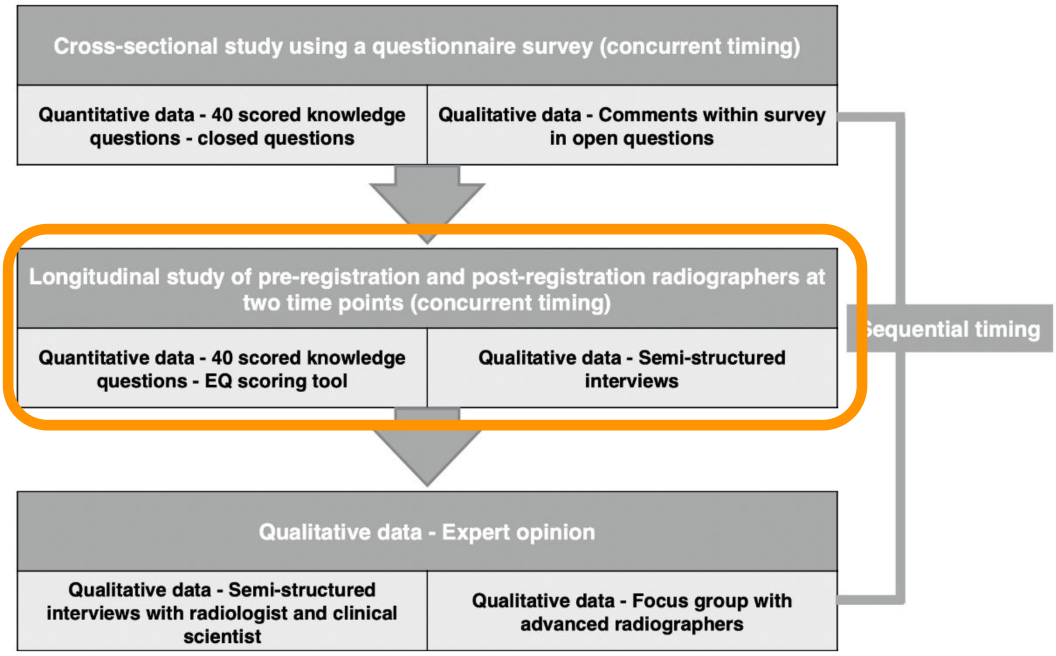

Figure *8.1 - diagram of the research design- phase2-Longitudinal study*

8.2 Background

Undergraduate courses in radiography and imaging are accredited by the HCPC and the College of radiographers which gives undergraduates the opportunity to be registered on qualification since they meet all the entry requirements for the register (HCPC, 2013). All undergraduate courses must have the capacity to train students in a wide range of examinations, with staff who are trained to support students in the clinical environment (Society and College of Radiographers, 2021b). Academic institutions combine theory and practical within a university X-ray room, and some have access to CT scanners or virtual classrooms to prepare the students for clinical placements (Society and College of Radiographers, 2013). Radiography students at this university attend their first clinical placement in the first year of the programme; Hyde (2015) describes students feeling nervous and unsure before attending placement and recommends that students have a carefully planned curriculum to prepare students for the clinical environment before their first block of placement with improved clinical support during the placement. Attrition rates among student radiographers are high and the experience of the clinical placement may account for some of the attrition (McAnulla et al., 2020). The 2019-2020 UK diagnostic radiography attrition rate for undergraduate courses was 16%, which is higher than other undergraduate courses (McAnulla et al., 2020; College of Radiographers, 2022).

The structure of programmes means that by the end of the third year, students are familiar with the clinical environment although learning more complex skills such as cross-sectional imaging and ultrasound, students may feel anxious about these modalities and be aware that their skills in other areas may be dwindling (Naylor et al., 2015). The transition from student to newly qualified radiographer is dependent on the student experiences of the clinical environment and is softened where student radiographers feel more like one of the team (Naylor et al. 2015). Most hospitals include extensive preceptorship programmes to welcome newly qualified radiographers and to make sure they have the knowledge and skills required for the imaging department (Sloane and Miller, 2017). The preceptorship is supported by a comprehensive competency assessment programme. Vosper et al. (2005) investigated destinations of students after leaving the undergraduate radiography course, 89% of the students were employed as radiographers and only 16% were planning to leave in the next five years. However, recent improvements in induction programmes for newly qualified radiographers may help to reduce the attrition rate of newly qualified radiographers further while the high demand for radiographers may increase satisfaction rates. Nightingale et al. (2021) cited lack of timely progression and CPD as negative influences that could affect retention. When newly qualified radiographers start in a new modality there may be a sub-culture within that modality which they need to become familiar with, and they may be nervous especially within CT due to the illness of the patients combined with the technical complexity of the modality (Sloane and Miller, 2017).

At this point the students have left the protected academic environment and their training is now influenced by the people around them both technically and emotionally.

8.3 Method

For the second interview, students (now post-registration radiographers: PRR) were contacted and asked if they had spent time in CT scanning and whether they were willing to be interviewed; two of the original sample could not be contacted. Seven students were interviewed at point 1 and point 2 of the longitudinal study. The second interview took place at a mutually agreed public area or their place of work. Where the interview took place in an NHS Trust, permission was sought from the imaging services manager, and a risk assessment needed to be signed off for each interview. One interview took place via FaceTime. Arranging the interviews at the NHS Trusts was complex and took months to arrange. The scheduling of interviews was carefully thought out to give minimum disruption to the radiographer (PRR).

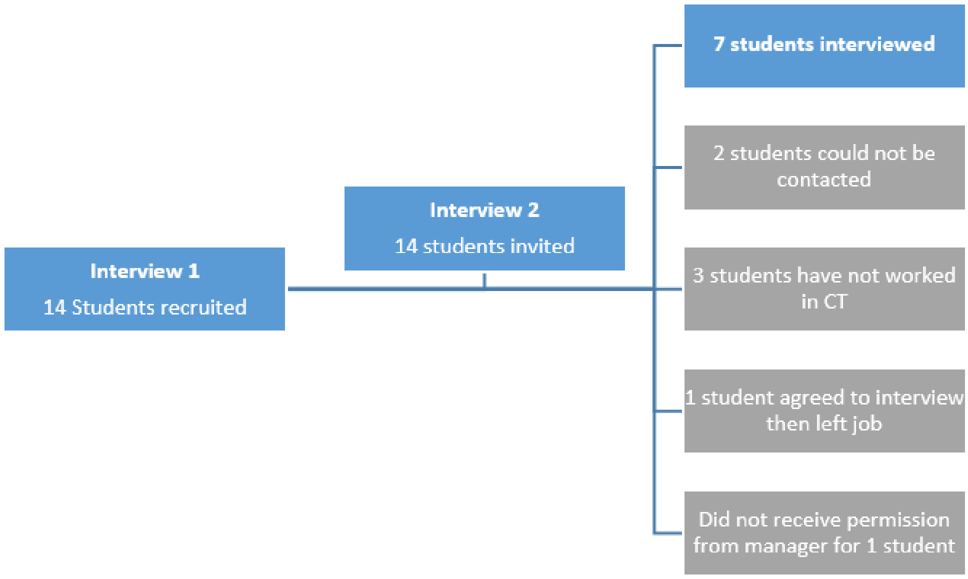

Figure *8.2. Schematic diagram of participants in longitudinal study.*

The second interview took more time than the first because as PRR they were more confident and were able to talk about their opinions and experiences freely. The first interviews were easy to transcribe but the length of the second interview, approximately 30 minutes in most cases, made self-transcription prohibitive even with transcription software, thus an academic confidential transcription service was used.

Ethics

The application for ethics for this longitudinal study was approved by the University of Hertfordshire Ethics Committee with Delegated Authority HSK/UH/02331 from 11/03/2016 until 01/06/2017 this was later extended until 01/06/2018 (aHSK/UH/02331). The extension was required because the longitudinal study involved interviewing final year undergraduate radiography students and then re-interviewing them when they have spent a year in CT scanning in their first post as radiographers. Some of the participants interviewed did not get jobs straight after qualifying and some did not get rostered into CT scanning as newly qualified radiographers, so more time was needed to capture their experiences of CT scanning. Relevant permissions were obtained.

8.4 Findings

Results were analysed via descriptive statistics, EI scoring and thematic analysis. Mean scores of the group were compared with the groups in the previously published study and the cross-sectional survey, which were analysed using the same method. Open-ended interview questions providing qualitative data were coded and trends emerged which identified the main themes.

8.4.1 Quantitative data

The second part of the longitudinal study included seven post-registration radiographers, with a mean age of 26 (21 – 50), 29% were male, three students obtained a first-class degree, one 2.1 and three 2.2. Two of the original participants could not be contacted. Over a third (4/11) of the PRRs had not worked in CT since qualifying. Just under a third (3/11) of PRRs had started working in CT between 6 months and 2 years post qualification.

Over a third (4/11) of the PRRs started working in CT within 6 months of qualifying, these PRRs received minimum training.

The newly qualified radiographers who were working alone in CT while on-call worked under agreed protocols, mostly undertaking head scans. They were working under the direction of the radiologist but at night the radiologists were not local but from reporting houses and may have been based outside the UK.

Protocol and parameter questions

Table 8.1- Comparison scores between UK radiographers and pre-registration and post-registration radiographers.

Profession	*n*	Mean	SD	Min	Max
UK radiographers	47	29	3.7	23	36
Pre-registration	14	24	4.5	16	31
Post-registration	7	29	3.4	27	35

As in the longitudinal 1 study the Kolmogorov-Smirnov Test of Normality was carried out on each set of data. The result of the test for normality revealed that the data does not differ significantly from a normal distribution. This means that a parametric test could be run on the data because for parametric tests to be reliable the data has to be approximately normally distributed (Samuels and Marshall, 2013).

A t-test for independent means was carried out firstly between UK radiographers and students point 2 and then students point 1 and students point 2, the numbers of participants differed in each group, so a paired *t* test was not used. The hypothesis being that there was no significant difference between the groups. A two tailed test was used because the distribution was symmetrical (*t* distribution) the test was for positive or negative differences in the two groups.

t-test 1

When the 47 participants in the UK radiographer group (M= 28.55 SD= 3.7) were compared to the 7 participants in the post-registration group (M=29 SD= 3.4) there was no significant differences in the scores $t(43) = -0.49$, $p=.627$

When these results are put through a G*Power 3.1 calculator, power was calculated as 0.6 which is much smaller than the desired power of 0.8 indicating the sample size was too small (Faul et al., 2009; Stangroom, 2021).

t-test 2

When the 14 participants in the pre-registration group (M= 23.64 SD= 4.5) were compared to the 7 participants in the post-registration group (M=29 *SD*= 3.4) the result demonstrated a significantly higher score $t(20) = -2.93$, $p=.0085$

When these results are put through a G*Power 3.1 calculator, power was calculated as 0.78 which was just less than the desired power of .80 indicating the sample size was just under the desired size (Faul et al., 2009; Stangroom, 2021).

The results show that the score of the UK radiographers who participated in the national survey is not significantly different from the post-registration radiographers. The score of the post-registration radiographers is significantly different from the pre-registration radiographers score, so over time the post-registration radiographers have gained more knowledge of CT exposure parameters which is desirable.

t-test 3- Paired t-test

When the matched scores of the 7 participants who participated in both parts of the longitudinal study were compared the result demonstrated a significantly higher score t(13) $p = 0.037$ The result was significant at $p<0.05$

Mean for longitudinal study part 1 = 28.6, SD = 4.5 Mean for longitudinal study part 2 = 29, SD = 3.4 When these results are put through a G*Power 3.1 calculator, power was calculated as 0.09 which was less than the desired power of 0.80 indicating the sample size was under the desired size (Faul et al., 2009; Stangroom, 2021)

8.4.2 Qualitative data

Three themes were identified in the qualitative data which were:

Education

Dose optimisation

Culture

Education

When interviewed for the second time the post-registration radiographers explained that their training had been undertaken by the qualified members of staff in the department. They had become familiar with general radiography, and most were progressing from a band 5 to a band 6 role. They had received comprehensive bespoke induction programmes for CT scanning and were making the most of the in-house training opportunities. Most of the PRRs felt very well supported for academic education and technical training within their department.

Table 8.2 - *Frequency table - Education -sub themes*

Sub-category	Number*
On-the-job training (including radiographer/clinical scientists & radiologist talks/training)	12
Applications training/talks	4
Undergraduate training	3
Postgraduate training	5

*Numbers are individual mentions.

Four sub-themes were identified

1. On-the-job training
2. Applications training
3. Undergraduate training
4. Postgraduate training

On-the-job training

The sub-theme of on-the-job training attracted the most comments which matched the first set of interviews in the longitudinal study. The radiographers continued to feel that this was the best source of training. Most of the students had a positive experience of in-house training in CT scanning. In-house training was delivered by radiographers, radiologists, and clinical scientists. Some of the in-house training was more formal than others.

Figure *8.3 -Mind map for on-the-job training sub-theme*

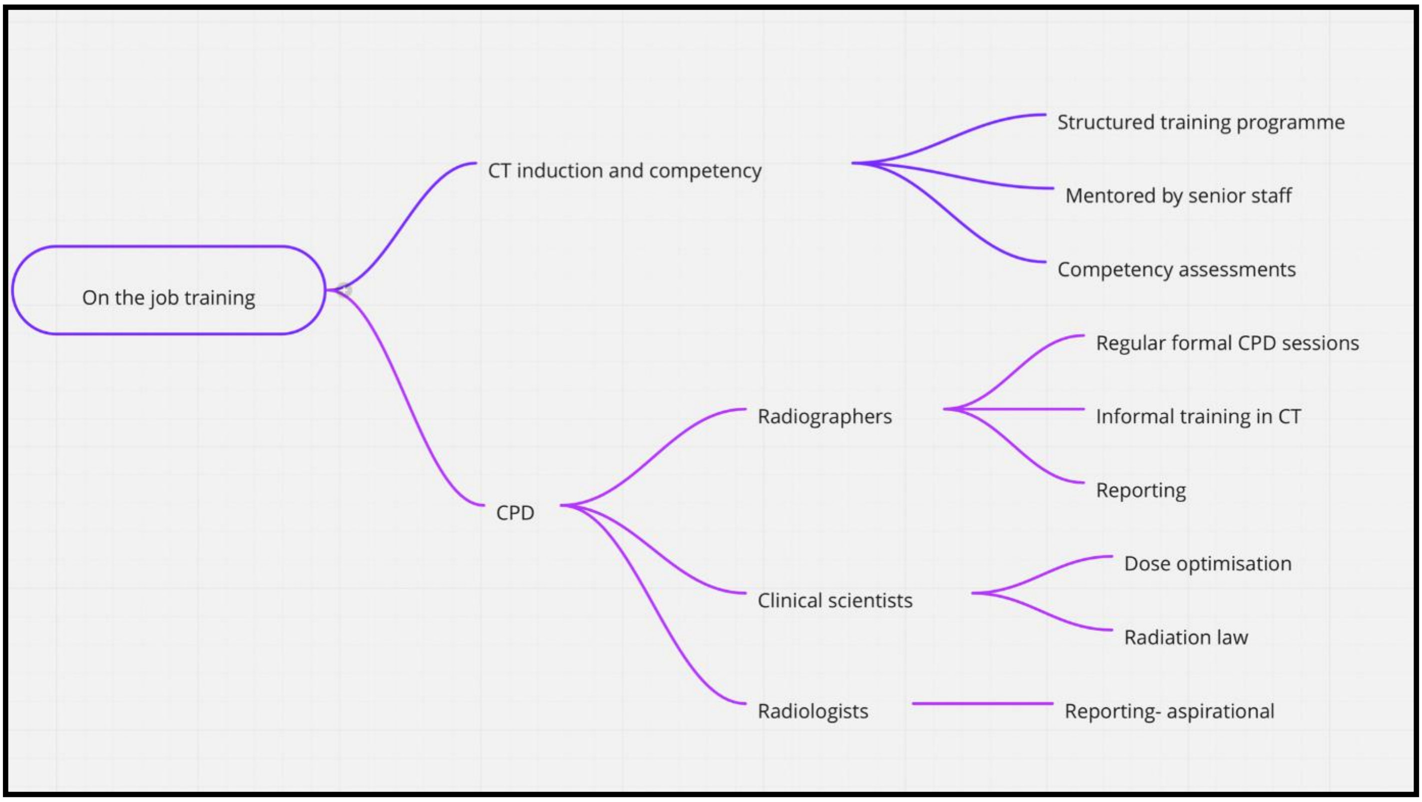

Table 8.3- *Post-registration radiographers' comments*

"Since we've have got new people, they have got a competency checklist" *PG7*

“They are great teachers that know a lot like a fountain of knowledge, and they are very happy to share it, so you learn an awful lot even with the odd day just here and there. It’s been really good” *“PG14*
“We have structured training, going to CT in afternoon. It is a new type of training here. We take on the ARA (Advanced Radiographic Assistant) role and spend the afternoon in CT, which frees up ARAs to go elsewhere”*PG10*

At a few Centres clinical scientists were involved in the In-house training which helps with the understanding of radiation law, radiation dose and quality assurance of the equipment. It is a recommendation of the COMARE response report, and it is good to see that it is now occurring in clinical practice (Chell, 2016).

Table 8.4 *Post-registration radiographers’ comments*

“We have sessions with physicists as part of our training” *PG10*
“We had like those CT dose tutorials with the medical physicist there but not the radiologist” *PG5*
“Somebody did a dose reduction course, but they only focused on X-rays, not CT” *PG4*

Some expressed an interest to attend a reporting session with a radiologist or reporting radiographer. There is a chronic shortage of radiologists, and the way forward is to train radiographers to report, there is a shortage of radiographers especially ones who are able to undertake cross-sectional imaging but there would be a great benefit to empower radiographers to report CT scans as opposed to sending the scans abroad to outsourced reporting houses (Culpan et al.,2019). In their recent report on radiology workforce, The Royal College of Radiologists (2021) report explains that 33% of current consultant radiologist post are vacant. Two of the four RCR priorities relates to radiographers reporting by investing in the wider diagnostic team and better use of skills and experience of the workforce (The Royal College of Radiologists, 2021). Woznitza et al. (2014) found that CT examinations increased by 23% in their three-year study, they believe that when radiographers and radiologists work together to provide a reporting service the patient pathway is improved and scans are reported in a shorter timeframe of 0.7 weeks for a CT scan, with the radiographers reporting the projectional X-rays. Currently only a handful of radiographers are reporting CT scans (Culpan et al.,2019).

Table 8.5- *Post-registration radiographers' comments*

"I think it would be really nice to sit with a radiologist maybe when they're reporting the CTs because you get so much from that, the things that you don't notice" *PG7*
"……….. it's the same with plain CTs, like I love sitting with the reporting radiographer" *PG7*

In their first interview the students seemed to be much more aspirational about reporting CT scans by attending postgraduate training, but they may be currently exhausted with the day-to-day learning of the technical aspects and patient care in this complex busy modality.

All the departments the radiographers were working in were providing comprehensive CPD within the department, the radiographers were not able to attend all the CPD on offer, but they did have the opportunity to learn whilst at work.

Table 8.6- *Post-registration radiographers' comments*

"It's an advantage that the people who actually know these things can do the teaching sessions" *PG4*
"Lots of CPD sessions. Do them almost every week now. I wouldn't say at lunchtime , they do organise them every week but not everybody can go to everyone. Somebody has to stay behind" *PG4*

Williamson and Mundy (2010) looked at role development in newly qualified radiographers and its effect on job satisfaction, 97% of their participants expected their role development opportunities to be realised within the first five years in post. Nightingale et al., (2021) cited that a lack of timely career development and CPD opportunities as one of the reasons radiographers were leaving the profession so its importance should not be underestimated.

In-house training is cost effective and makes training available to everybody in the department the only caveat being that the people training need to have the knowledge to train people. This was pointed out by participants, in the first stage of this study, responding to the national survey and by Sloane and Miller (2017) who explained that there is a lack of postgraduate training so the teaching they are doing may be from knowledge they acquired as students which may not have been updated.

Applications training

Four of the PRRs felt that they would like to receive applications training but none of them had attended any applications training either in the department or at a 'users group meeting'. Junior staff were performing scans alone at night they were not deemed CT radiographers, so applications training was cascaded down to them by senior staff. Manufacturers have a responsibility to communicate aspects of the design of the scanner to the users so optimum images can be obtained with the lowest dose possible, this is partially important since the scanners are becoming more. technically complex and specific patient groups such as children are likely to be affected by the radiation dose (Strauss and Kaste, 2006).

Table 8.7- *Post-registration radiographers' comments*

"Would like to see an application specialist if they came in to show you how to programme the scanner"*PG4*
"A Toshiba users 'day, it might be useful yeah" *PG6*
"A message comes up if the scan times too long, to increase the kV and decrease the dose index, but I don't know why I'm doing that*" PG7*
"…. I had a KUB- I'm not a CT radiographer, I only do it when I'm doing nights" *PG13*

Undergraduate training

Three participants reflected on their undergraduate education but did not express how they would change the way new students are taught. Only the radiographers who had worked in CT scanning were interviewed a second time in this study, so it is hard to say if the other radiographers felt that learning CT heads at undergraduate level was useful. For most radiographers this is the only formal academic CT training they ever receive, and it sets the foundation for other on-the-job training.

Table 8.8- *Post-registration radiographers' comments*

"I feel it's probably more knowledge-based than back when I was a student in terms of practical knowledge rather than just book knowledge"*PG14*
"I would love more training in to understanding this kind of properly and all the protocols and changing things, and yeah I have no time to focus on anatomy and all the stuff I love" *PG7*

Postgraduate training

The radiographers felt that postgraduate education would be useful for specialist techniques such as cardiac CT scans and CT colonography. There was a perception that they might need to pay for themselves and attend in their own time, government masters' funding may be available for some courses.

Table 8.9- *Post-registration radiographers' comments*

"I'm not sure there is time in the day, I think I'd have to go to a course in uni or in my own time" *PG7*
"I would like to attend courses for advance technique." *PG5*

The CQC 2020/19 IR(ME)R report (2020) pointed out that radiographers should not act as IR(ME)R practitioners for CT examinations unless they have received post-graduate training or additional training since practitioner training is not covered sufficiently at undergraduate level.

Dose optimisation

The radiographers were working in CT scanning mostly at night during on-call and were performing non-contrast CT scans mostly under protocol, which is common practice in the UK and the CQC (2019) refer to it as level 1 CT scanning. Several were expanding their scope of practice and aspired to being CT radiographers. The radiographers were thinking much more about radiation dose and how to use the equipment now they were autonomous practitioners.

Dose optimisation results

The analysis of the data from the participant interviews showed four sub-themes:

1. Exposure parameters
2. Dose Modulation
3. Metallic Implants
4. Collaborative working

Table 8.10 - *Frequency table - Dose optimisation sub-theme*

Sub-category	**Number***
Exposure parameters	27
Dose modulation	7
Metallic implants	6
Collaborative working	10

*Numbers are individual mentions.

Exposure parameters

The CQC is concerned about CT scanning because of the previous large number of notifications leading to high radiation dose incidents with the sub-modality. The 2019/20 CQC IR(ME)R (2020) report was no exception with the highest number of notifications being reported from CT scanning accounting for 68% of diagnostic imaging notifications. There was an opportunity to reduce patient's dose in one of the CT notifications in the report by adjusting the scanning parameters and field of view, radiographers must be aware of how to do this in the clinical environment (CQC, 2020). Sixty percent of the radiographers were not aware that increasing the kVp from 120-140 kVp increases the CTDI value by 38% which was a poorly answered exposure parameter question (Foley et al., 2013). It is important for radiographers to understand the consequences of changing exposure parameters.

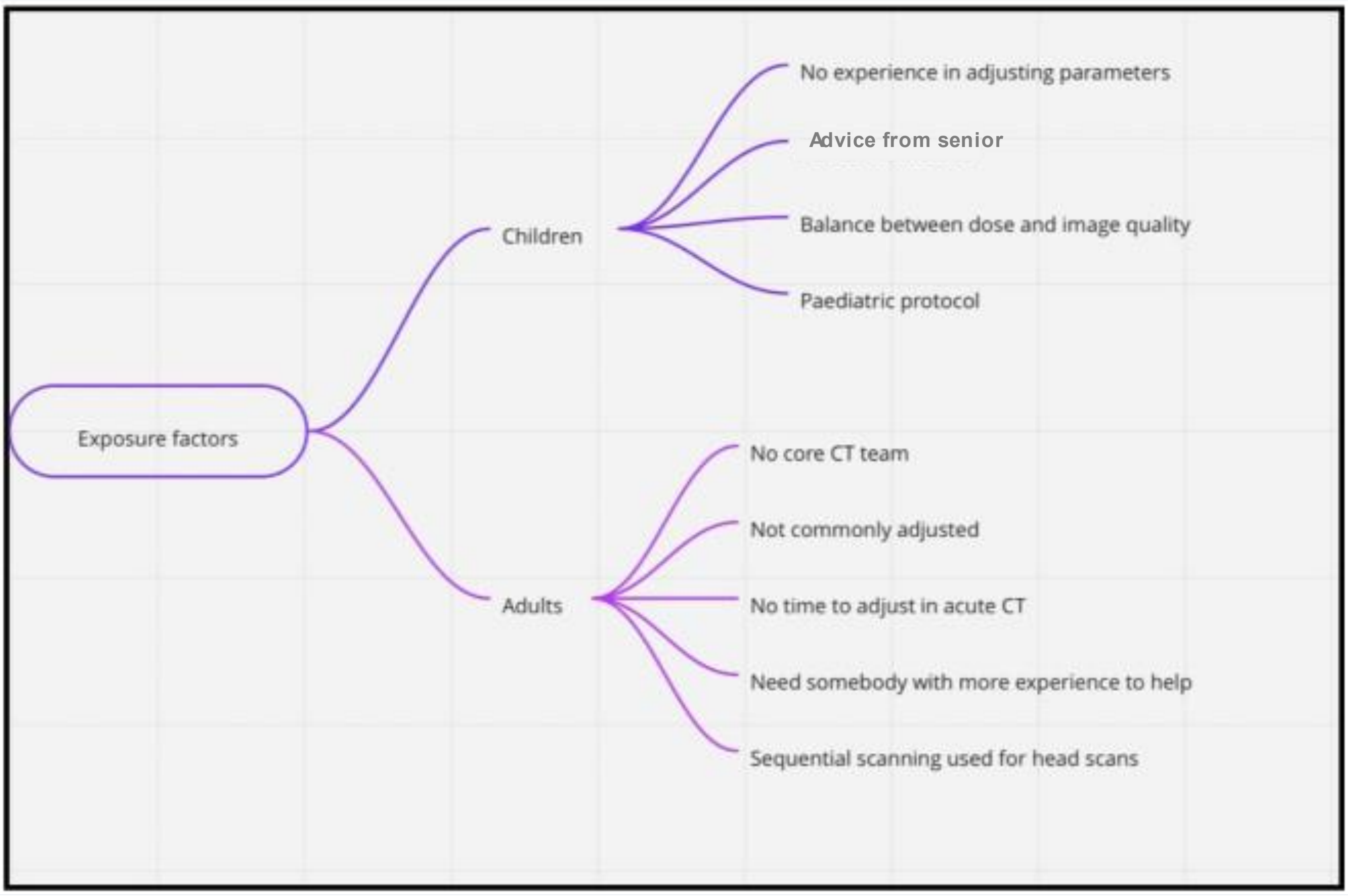

Figure *8.4 – Mind map exposure factors sub-theme*

The radiographers spoke about adjusting exposure parameters in their clinical environment.

Table 8.11- *Post-registration radiographers' comments*

"(Adjust exposure) it would normally do it automatically"*PG6*
I might have in my head, "Like oh I'll go down to the lowest", which I think is 80. I think it's mainly set up at 120 so we can go down to 100 or 80. But then it depends how big they are; you need to judge it when they come round. PG7
"The exposure parameters would not need to be as high. Often the machine would calculate it automatically, we would expect the exposure factors and the dose given at the end of it to be a lot lower. Both for the radiation protection of the child and because not as much exposure would be needed to produce diagnostic results." *PG13*
"There is like a protocol called kV assist so when we have the smaller patient and we use the kV assist we can tend to bring the dose down so it's much lower than non-kV assist protocol." *PG5*

One radiographer spoke about using sequential scanning for head scans because helical scanning scans outside the delineated field of view in the z axis, which can deliver a higher effective radiation dose to radio-sensitive areas just outside the field of view such as the lens of the eyes (Tzedakis et al., 2005). Sequential head scanning is the traditional way of scanning, but Van Straten et al. (2007) found that thinly collimated spiral CT produces enhanced image quality.

The radiographers appreciated the need to adjust exposures for children although they made not have seen the adjustments in practice at this stage of their careers. They were aware that they may need to ask for help from a senior CT trained member of staff.

Table 8.12- *Post-registration radiographers' comment*

"5-year-old child ……. change the paediatric one." *PG4*
"So, if it sets the child exposure, you would keep that, but you would make sure that the dose is as low as reasonably possible for it. So, it would be closer to 80 kV or 100 depending on what the lowest settings are. (Paediatric protocol) I haven't seen it but I'm guessing there must be" *PG6*
MPE has set paediatric settings on weight of child in kgs. *PG10*

The International Commission on Radiation Protection (ICRP) (2013), Radiation Protection in Paediatric and Interventional Radiology publication, advocates that dose reduction in CT for children should be optimised by adjusting scan parameters such as mA, kVp and pitch according to age or weight and that images with greater noise should be accepted. The CQC IR(ME)R specialist paediatric radiology services report (2017) informs that the number of paediatric CT examinations increased over 36% between 2012 and 2017, children are not only scanned in a specialist paediatric setting, so radiographers are likely to be expected to scan children in their working lives.

Dose modulation

Dose modulation is the way the scanner is programmed to automatically change exposures to produce an optimum image with the lowest dose. Some dose modulation software just changes the tube current (mAs), automatic tube current modulation (ATCM), but more modern equipment can change the tube current and the tube potential (kVp) (Layman, 2021; Papadakis and Damilakis, 2019). The operator has a part to play because the information obtained from the scout view is used for the automatic exposure control (Vosper et al., 2021). The operator must position the patient in the middle of the scanner gantry both horizontally and vertically, the isocentre, and then select the correct field of view when acquiring the scout (topogram) view. If the operator sets an incorrect FOV, for instance starting at the top of the head instead of the top of the chest, and then moves the patient position to fit the FOV then the scanner will have an algorithm to select a higher kVp and or mAs through the head as opposed to the chest which is mostly air, the scan when undertaken will then give a high dose to the chest and a low dose to the abdomen. It is therefore essential that the operator repositions the patient and performs another scout view with the current patient positioning. This small amount of extra patient dose, from the extra scout view, will benefit the patient since the CT scan will be acquired with the optimum dose and image quality (Joyce et al., 2020)

Table 8.13- *Post-registration radiographers' comments*

"Could make manual adjustments but this is not encouraged."*PG10*
"With the positioning at a certain point." *PG5*
The centering of the patient, we have got to make sure that they're in the isoentre; not too high, not too low.*PG7*
"Incorrect positioning for scout view, I don't think it matters here. It automatically adjusts to work out."*PG6*

Once the patient is setup correctly the operator can select preset parameters for different body forms or manually change the exposure parameters. Most Centres do not let individual operators change exposure parameters because a small change can change the patient dose dramatically.

Table 8.14- *Post-registration radiographers' comments*

"On one of the scanners we have a HD scanner and there is like a protocol called kV assist so when we have the smaller patient, and we use the kV assist we can tend to bring the dose down so it's much lower than non-kV assist protocol."*PG5*
"Mainly, if its paediatric you're in that mind set of changing and picking different things, but day to day, unless there is an obvious, bigger or smaller, I don't (change parameters)."*PG7*
"You would have to consider the maximum tube current allowed. Whether you would need to increase or decrease that, you'd have to consider the patient size and the area being scanned"*PG14*

Metallic Implants

In part one of the longitudinal study, one of the most poorly answered questions was the use of dose modulation software when a patient has a metallic implant. Foley et al. (2013) also found that this question was poorly answered in this survey. The post-registration radiographers seemed to have expanded their knowledge since being in practice and most were using the automatic dose modulation even when the patient had a metallic implant. They also mentioned the reconstructions which could be used to alleviate the beam hardening artefacts caused by the metallic implant. Despite the radiographers' practical knowledge 60% did not answer the exposure parameter question correctly. One comment did indicate that the post-registration radiographer may turn off the automatic dose modulation.

Table 8.15- *Post-registration radiographers' comments*

"Metallic implants and stuff, we have a separate scanner that we normally do, people with any sort of metal"*PG7*
"Oh, this person has got a double hip replacement, they're going to have a beam hardening artefact, therefore we should maybe turn off AEC"*PG12*
"We have the iMARS – the implant metal artefact reduction."*PG5*

Collaborative working

Most of the radiographers were supported by clinical scientists and they had built up a good relationship with them. At this stage they were being taught by the clinical scientists and were not involved in protocol development.

Table 8.16- *Post-registration radiographers' comment*

"We had like those CT dose tutorials with the medical physicist there but not the radiologist if I'm not mistaken but the CT team and the medical physicists are there." *PG5*
"*MPE has set paediatric settings on weight of child in kgs.*"*PG10*

The post-registration-radiographers were aware that radiologists were involved in protocol development with radiographers and colleagues.

Table 8.17- *Post-registration radiographers' comments*

"Radiologist decides on protocol including recon." *PG5*
"*We had a chest specialist who said give me a low-res image not high res whereas others always asked for a high res. but for him he was more than happy to report on that. It just depended on which radiologist you spoke to. They would specify which protocol they would want.* "*PG4*
"So, I've seen the radiologists and the radiographers work together for biopsies and interventional procedures" *PG14*

Culture

This section was the hardest to analyse, comments were long and did not fit cleanly into sub-themes at first. The second in-depth interviews were two years after the first interviews and in most cases the post-registration radiographers had been accepted well into the departments as radiographers. They felt part of the team and were given opportunities to learn and progress their careers. This was echoed by the increase in well-being scores in the EI questionnaire (See Chapter nine). The post-registration radiographers had moved from a passive role identified in the first part of the longitudinal study to an active role absorbing all the information they could from their clinical surroundings. One post-registration radiographer had moved jobs and was finding the culture of her new department challenging. There was still a feeling of being early in their careers, but they were embracing the opportunities given to them. They learn how to deal with more complex situations and demonstrated increased emotionality.

Table 8.18 - Frequency table – Culture

Sub-category	**Number***
Active role	15
Team working	10
Nurture	6
Autonomous practitioner	13
Negativity	4

*Numbers are individual mentions.

Five sub-themes were identified:

1. Active role
2. Team working
3. Nurture
4. Autonomous practitioner
5. Negativity

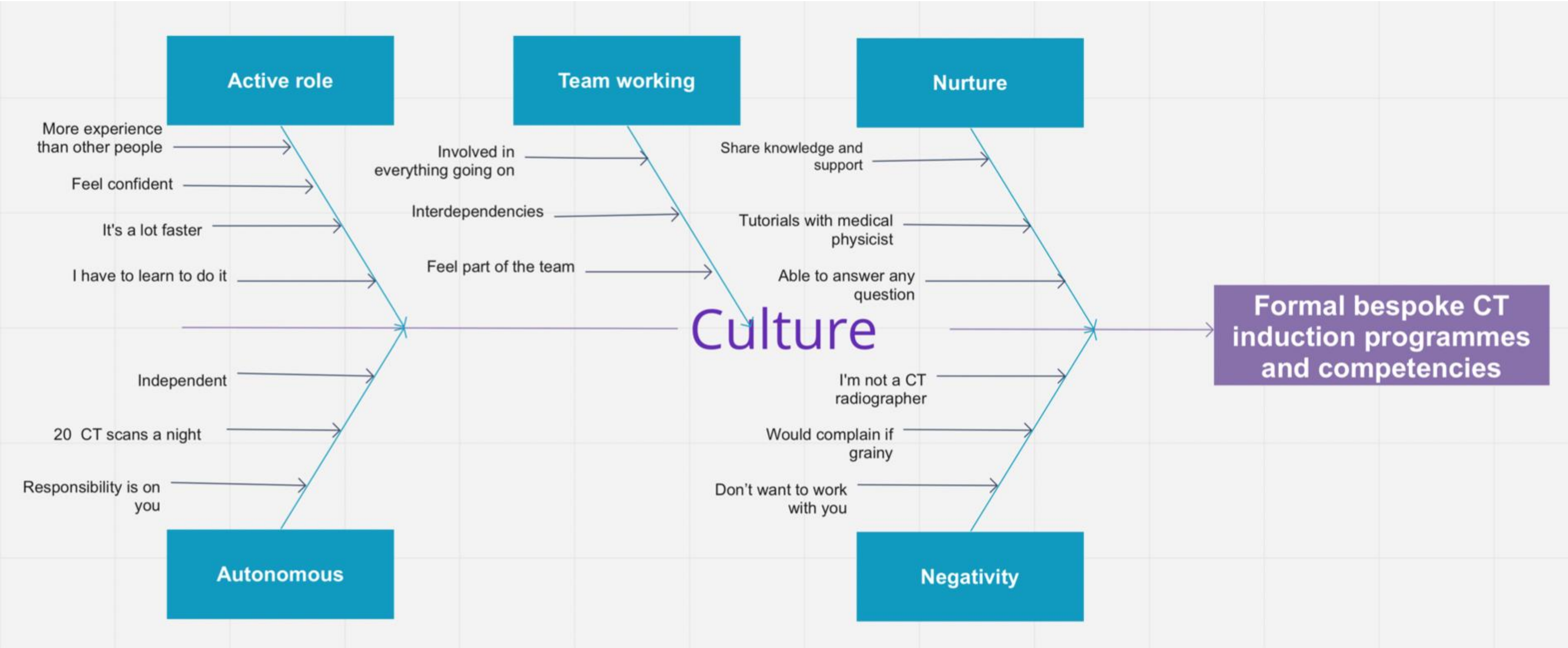

Figure *8.5 - Fish diagram for culture theme*

Active role

After two years in post, the post-registration radiographers were undertaking an active role as opposed to the passive role they played as students. The participants grew both emotionally, socially, and technically. They felt like a member of the team and did not shy away from busy departments since they felt that being busy was an excellent way of learning and they felt lucky to have the experience of scanning patients in CT.

"Crazy, nonstop" *PG7*
"*So, you get your workload, it's a lot faster and you get more range of patients coming in" PG13*
"20 scans in a night shift" *PG6*
" (head scans) I'd say I was confident with at first, but now we do the CTPA's, Angio's; we end up doing all sorts on night shifts" *PG7*
"They did allow us to do bank shifts over the weekends. So, if you wanted the experience, you would just give up your extra time." *PG4*

Table 8.19- *Post-registration radiographers' comments*

Liang et al. (2010) surveyed newly qualified radiographers in Australia, they found that due to their undergraduate experiences, radiographers were well prepared for their role. This concurs with the participants in this study. The post-registration radiographers felt well prepared for work as radiographers, due to their previous clinical experience underpinned by their theoretical knowledge

Table 8.20- *Post-registration radiographers' comments*

"It has boosted my anatomy and what I have learnt from uni makes more sense now, the physics part makes more sense" *PG13*
: .. so, I sort of had quite a lot of knowledge and worked in CT before" PG7
"It's probably because I stayed in the same place, I think I've always known what to expect when I came here" *PG14*

Some post-registration radiographers felt the difference between being a student and being newly qualified and felt much happier as a qualified member of staff making decisions themselves. Harvey-Lloyd et al. (2019) found that that newly qualified radiographers found the first three to six months stressful and that their participants had to spend this time understanding the culture of the new environment becoming part of a new community. The radiographers in this study had spent almost two years in their departments so they were familiar with their department culture but were now having to navigate the sub-culture of CT scanning. Decker (2009) who looked at historical accounts of newly qualified radiographers (from 1950-1985) concluded that radiographers had to learn about the job, the organisation and themselves when they started this still holds true.

Table 8.21- *Post-registration radiographers' comments*

"If you think back to how they treated you when you first began then at least you would turnaround ………. and say you know what just show me what to do" *PG4*
"I was so much afraid to confront it, but I'm not saying it's easy, but I have positive opinion now rather than when I was in uni" PG13

This concurs with the increase in ‘well-being’ scores from student to qualified radiographer in the emotional intelligence scores.

Team working

The radiographers felt that they were members of the team and were embracing the culture of the fast pasted technically complex environment. The RCR and SoR (2012) joint paper on team working in clinical imaging advocate that:
Patients receive a higher quality of care when healthcare teams work effectively.
When teams work together, they have relatively low stress levels.
There is more innovation in patient care when healthcare teams work together.

Table 8.22- *Post-registration radiographers’ comments*

“From the first day we are involved in everything” *PG10*
“….. because you want to feel part of the team and when you’re not cannulating, you can’t be a fully competent member of the team”*PG7*
“(Night shift) I would often see a lot of CT in there, because you would have to give them a hand, sizing the patient and all that, so they would do some teaching whilst we were doing that, which was quite good” *PG14*

Nurture

Participants found that peer support was available along with bespoke training programmes and competency assessments to enable them to work effectively in CT (Houghton, 2014). Hutton and Eddy, (2013) explained that managerial and organisational influences can affect job satisfaction, the participants in this study felt supported and nurtured and were happy with their role in the department. Several of the radiographers were progressing from band 5 to 6 at the time of their second interview. Competency frameworks helped the radiographers gauge where they should be in their training and provided a structured format for learning. The radiographers felt supported in the departments and were aware that they were not expected to work outside their professional boundaries.

Table 8.23- *Post-registration radiographers' comments*

"The head of CT is always working in the CT department because they were short staffed, so he knows day on day what's going on in there" *PG4*
"We're encouraged to ask all sorts of questions on anything that we see"*PG10*
"...was doing it before I was born. They are very experienced very knowledgeable and happy to share all that knowledge and teach" *PG14*
"They won't expect you to do things you can't do" *PG14*
"When I started, I got quite a nice induction, where I could just concentrate on learning and go off and do things and shadow people" *PG7*

Autonomous practitioner

In the HCPC standards of proficiency for registrant radiographers, standard 4 states that: "radiographers must be able to practice as an autonomous professional, exercising their own professional judgement" (Health and Care Professional Council, 2013). The post-registration radiographers were succeeding in being autonomous practitioners due to their hard work and enthusiasm as evidenced in the team working and nurture comments.

Table 8.24- *Post-registration radiographers' comments*

"…we were pretty much independent, which I think is a good thing because you get more experience" *PG10*
"I've learnt a lot and sometimes you have to make decisions yourself, you have to, it has really helped me" *PG13*
"So normally we are split up most of the night, 1 person is in CT all, 1 person in A/E all night"*PG7*
"……you have a bit of knowledge behind it and actually make a decision" *PG4*

As students most of the post-registration radiographers did not have the opportunity to develop autonomy in CT scanning, which should be an essential part of clinical practice experience (Fowler and Wilford, 2016). In the previous chapter pre-registration radiographers made the following comments about their clinical time in CT scanning:

Table 8.25- ***pre-registration*** *radiographers' comments*

“Don’t show us how to use, just click on this and that not really explaining it” UG3
“…if you get stuck doing one thing one way you think it is the only way to do this thing” UG14
“……. students just helping patients getting on and off table.” UG3

Most of the radiographers had bespoke induction programmes to enable them to work in CT while on-call at night. Some only scanned heads but others scanned a wider range of examinations. Sloane and Miller (2017) explained that departments had developed considerable induction programmes and in-house training for new graduates to enable them to work within their scope of practice especially for cross-sectional imaging, with one of their participants commenting that junior staff are taken from general radiography to CT and they end up doing the most complex work in the department.

Table 8.26- *post-registration radiographers’ comments*

“For our night shifts you need to be CT competent with the emergency scans to do the night shifts, so we do, do them as band 5” *PG7*
“Normally it's part of the induction, it's meant to be, but it was kind of a bit rushed, but I did get some later on.” *PG13*
“Every 3 months you would go there for a week as long as you didn’t get transferred back to generals”*PG4*

“We have a structured training, going to CT in the afternoon” *PG10*

Negativity

Some of the newly qualified radiographers experienced some negative attitudes from radiographers and radiologists. As qualified radiographers they understood the unfairness and reflected on the negative attitudes as opposed to taking a passive role they did as students.

Table 8.27- *post-registration radiographers’ comments*

“So, they would complain if it’s so grainy, in spite of the scanner being old- they expect you to adjust the protocol, choose the right protocol to bring an ultimate image” *PG13*
“But they refused one ……. I thought it was quite serious, but they were annoyed with me for not consulting them” *PG13*

The radiographers experienced some subordination but instead of thinking they were inferior they processed it as a learning experience (Lewis et al.,2008). They were new to post and under IR(ME)R the radiologist as the practitioner would need to give direction to the radiographers as operators (The Ionising Radiation (Medical Exposure) Regulations 2017) [1322]). Some radiographers said that the radiologists would report back to them if they felt that things could be improved but there was no indication that mutual learning occurred with the radiographers teaching the radiologists about the practical aspects.

One radiographer did feel animosity by some of the experienced radiographers when they took up a new post in a new department:

Table 8.28- *post-registration radiographers' comments*

"They said I don't want to work with you because they don't know what they are doing, if I don't know what I am doing then tell me how to do it."*PG4*
"But instead of sitting down and showing us how it is done some treated you as if you were dumb, while others treated you well which was really good, and others just refused to work with you" *PG4*

This is totally unacceptable and as the post-registration radiographer pointed out:

"I think sometimes we take on the attitudes of the people who teach us, you forget what it was like when you began, and you start behaving like the people who are already there" *PG4*

McPake (2021) found that radiotherapy students who experienced negative attitudes and behaviours from radiographers found them damaging with a negative effect on the clinical learning experience and that positive comments enhanced learning in the clinical environment. Unfortunately, this type of culture exists in some departments.

8.5 Conclusion

After two years as registered radiographers one third of the original participants had not worked in CT scanning. Over the two years the radiographers' wellbeing and emotionality had increased giving them more confidence to commit to an active role within the department.

Radiographers were working in non-contrast CT; most had received an induction before taking on the role most with minimal additional training. CPD was provided within the departments, the radiographers preferred on-the-job training with CPD being delivered within the department. Since most qualified radiographers do not have postgraduate education in CT scanning their knowledge can become outdated so in-house training should be supplemented with academic/technical education. There was a culture of nurture, but negativity still existed in some departments.

The results of the exposure parameter questionnaire revealed that, some post-registration radiographers were still unaware how to change exposure parameters in practice, and some lacked the background knowledge. Overall, the post-registration radiographers' knowledge had increased from when they were students.

8.6 Robustness and external validity of study

Major, V., Ryan, S., O'Leary, D. *Exploring academic and social factors effect on CT dose optimisation- a longitudinal study of radiographers from student to first post.* Oral presentation, ECR Vienna 2019

Major, V., Ryan, S., O'Leary, D. *Exploring CT dose optimisation; a longitudinal study of pre- to post-registration radiographers.* Oral presentation, Health and Social Work research conference Hatfield 2022

8.7 Mapping the content of this chapter to the aim and objectives

The Aim of this study is to identify training requirements for UK CT radiographers regarding specifically social, clinical, and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation. This chapter partially met the aim, since it reviewed the current knowledge of CT parameters and their influence on patient dose and image quality amongst post-registration radiographers. Training needs were developed in this group of respondents in the longitudinal study. Social, clinical, and educational factors were developed in this chapter.

This chapter met the following objectives:

- to explore radiographers' knowledge of exposure parameters and view on education

- using a longitudinal study explore pre- and post-registration radiographers' knowledge and experience of dose optimisation within CT scanning
- using a longitudinal study explore the radiographers' educational experience
- using appropriate methods of analysis compare and contrast data with evidence base
- discuss combine and contrast emerging themes
- document the findings accurately and coherently for dissemination.

Chapter 9- Emotional intelligence

9.1 Introduction

Education and cognitive intelligence are not the only factors that affect the way a healthcare professional works or thinks; emotional intelligence and social intelligence has a part to play (Mackay et al., 2015; Zhoc et al., 2018). Golemen (2007) argues that Intelligence Quotient (IQ) cannot be changed by experiences in life since IQ is a genetic factor, but emotional intelligence can be taught and modified throughout life. Emotional Intelligence includes self-control, motivation, enthusiasm, and determination. The term emotional intelligence was devised by Salovey and Mayer, who believe it to be a subset of emotional intelligence and being the ability of a person to monitor their own other people's feelings and emotions, acknowledge the difference between them and process this knowledge to guide their thinking and actions (Mayer et al., 1990).

The brain is wired to connect with others using interpersonal skills (Goleman 2007) and thus since CT radiographers work in close teams during long shifts, each will influence the other emotionally.

General intelligence or cognitive ability is the ability to solve mental problems and is measured across all cognitive domains (Deary 2020). Spearman (1961) refers to general intelligence as 'g' and this has been the basis of intelligence testing since 1927 for IQ. Intelligence, IQ and g are distinct, intelligence refers to cognitive ability, IQ is an index of intelligence, g is a factor derived from and based on theoretical construct used by psychologists. Salovey and Mayer (1990) express the opinion that emotional intelligence (EI) may or may not correlate with general intelligence. Arora et al. (2010, p749) suggest that emotional intelligence is a different type of intelligence which, "involves the perception, processing, regulation and management of emotions". Golemen (2007) advocates that emotional intelligence can be taught and modified throughout life; Mackay et al. (2012) state that emotional intelligence is of value in healthcare settings since it influences interactions, which can affect patient care due to the fact it can be enhanced. Global emotional intelligence is measured with the validated trait emotional intelligence questionnaire (TEIQue) deriving a global intelligence score from a measure of well-being, self-control, emotionality and sociability (Petrides, 2009). Trait EI questionnaires are a self-reporting tool measuring normal behaviours in emotionally relevant situations and self-related skills (O'Connor et al., 2019). Trait EI tends to be a good prediction of actual behaviour because it is measuring normal rather than maximum performance (Petrides and Furnham, 2000). The disadvantages of Trait EI are that people are not always good judges of their own emotional abilities and people can report the result they feel the tester wants, not what they truly feel. This is an effect believed to be more common in industry as opposed to research (O'Connor et al., 2019). TEIQue is a widely used comprehensive measure of Trait EI which has evidence to support its reliability and validity (Petrides and Furnham, 2000; O'Connor et al., 2019; Andrei et al., 2016)

Mackay et al. (2012) required UK radiographers to categorise themselves into one of eight groups however most general radiographers also work in CT on a rotational working pattern; these authors thus concluded that UK radiographers scored higher than the normative sample in global EI traits but that the CT subgroup score was not significantly different from other subgroups perhaps due to the self-categorisation.

9.2 Emotional intelligence in radiographers

Emotional intelligence is considered an important skill in healthcare since high EI is associated with communication, teamwork and empathy leading to an enhanced standard of patient care (Nöthling et al., 2021). Mackay et al. (2015) explain that EI has proved useful in business for leadership, creativity and role suitability, and advocate that in radiography, in an emotional, complex, personal environment there are benefits of applying EI. There is belief that high levels of EI lead to effective critical thinking and clinical reasoning (Kaya et al., 2018).

As undergraduates, radiographers have several barriers to learning in the clinical environment. Fowler and Wilford (2016) highlight that student radiographers rarely work with the same qualified radiographer, and this leads to problems obtaining written feedback and having a discussion about their feedback to maximise its value. Undergraduate radiographers took a passive role in CT scanning due to the busyness of the department and were not considered a full member of the team. A low EI would be expected of the students under these circumstances since the global emotional intelligence (EI) score includes wellbeing, emotionality, self-control and sociality. Adults is believed to remain stable once reaching adulthood, but several studies have indicated that EI can be changed with educational interventions (Lewis et al., 2017a). An EI study of Australian radiographers found that undergraduate Global EI scores were significantly lower that the radiographers scores, and radiographers qualified 0-5 years less than 6-10 years, concluding that immersion in the clinical environment and role modelling influenced trait EI (Lewis et al., 2017a).

There was no evidence of any mutual learning between the student radiographers and qualified staff. Mackay et al. (2012) investigated whether people with high EI make good leaders and concluded that this is the case since people can use their positive emotions to inspire others in teams. This is therefore a possibility within the modality of CT. The team benefits because positive emotions can lead to enthusiasm and trust from well-managed interpersonal relationships inspiring team members to work well together and to support each other.

The main advantage of the current study is that the subjects are matched to themselves becoming their own control group. A disadvantage is that participants can become familiar with the TEIQue-SF tool having completed it twice.

The EQ questionnaire - TEIQue-SF tool (Appendix 2) was analysed online using the TEIQue-SF tool statistics package (Petrides 2009).

9.3 Emotional intelligence results

Table 9.1 - Emotional intelligence scores

Group	*n*	Pre-registration radiographers	*n*	Post-registration radiographers
Global intelligence- mean	7	5.13	7	5.43
Standard deviation (SD)	7	0.64	7	0.67

When compared to Mackay et al. (2012) the pre-registration radiographers' EI global score mean was similar to the UK radiographers' nuclear medicine group, which was the professional group with the lowest mean score. Turner et al. (2016) observed that students work more independently at the end of their course resulting in the same stresses as qualified radiographers. It is however possible that at this time-point the undergraduates had not yet developed the coping mechanisms required, hence the lower EI score. The EI global mean score did increase in the post-qualification radiographers, but when a paired t-test was performed the difference was not significantly different. The radiographers did increase their EI Global score to 5.43 which was similar to the published score (5.35) for general UK diagnostic radiographers in Mackay et al. (2012).

Each of the four subcategories were then compared separately via paired *t* tests.

Table 9.2 - Emotional intelligence subcategories and t test results

Group	**Pre-registration radiographers**	**Post-registration radiographers**	**t-test for dependent means**	**Value of *p* (Result is significant at p=.05)**
wellbeing - mean	5.5	5.9	2.6	0.039 power =0.25
Standard deviation (SD)	0.68	0.71		
emotionality - mean	5.4	5.8	2.5	0.047 power = 0.27
Standard deviation (SD)	0.67	0.63		
self-control - mean	4.7	5.5	0.15	0.89
Standard deviation (SD)	0.61	1.1		
sociality - mean	4.6	4.4	1.9	0.11
Standard deviation (SD)	0.86	0.76		

When the separate categories are compared by a paired t-test the results for wellbeing and emotionality are significant (Table 8.2). The raw data were tested for normality (Kolmogorov-Smirnov test) which indicated that the data for the global EI as well as all the categories did not differ significantly from normally distributed data. On the two categories that had a significant p value the samples were matched but the size was small (n=7) so when the data were tested via G*Power 3.1 calculator, power was calculated for wellbeing and for emotionality the results were 0.25 and 0.27 respectfully. Both numbers were below 0.8 indicating the sample size was too small. Unfortunately, the desired sample size was not achieved due to the attrition of participants from the study due to lack of time spent in CT scanning (3), being unable to contact the participants (2) and participants being unwilling or unable to participate in the second part of the study (2).

The feelings of wellbeing and emotionality is expected to increase after qualifying as a radiographer, especially since the PQR sample had their second interview two years after their first interview since it took most of them that length of time to work in CT scanning. Lewis et al. (2017b) found that during a three-year course students' EI did not change significantly, which was considered a surprising result. These authors acknowledge that Naylor (2014) found that newly qualified radiographers' awareness of departmental culture, and their own professional identify increased immediately post qualification and thus their EI would be expected to increase. Naylor (2014) did not measure EI in this longitudinal study but did explore how over time newly qualified radiographers gained confidence through awareness of their professional identity. In this longitudinal study the post-registration radiographers were asked about their experience in CT scanning, which they did not participate in immediately post qualification. They were already aware of the department culture, but they had to become aware of the culture of the CT modality which is a separate sub-culture (Naylor, 2014). Lewis et al. (2017a) found a significant difference between global trait EI, well-being and self-control when comparing undergraduate radiographers and radiographers qualified for more than five years.

9.4 Conclusion

In this longitudinal study, undergraduate radiographers had a significantly lower well-being and emotionality scores when compared to post-registration radiographers, while the global trait EI score and self-control scores remained constant. The second time point of the longitudinal study was two years post qualification and by five years the global trait EI and the self-control may have significantly changed when compared to undergraduate

9.5 Robustness and external validity of this study

Major, V., Ryan, S., O'Leary, D. *Exploring academic and social factors effect on CT dose optimisation- a longitudinal study of radiographers from student to first post.* Oral presentation, ECR Vienna 2019

9.6 Mapping the content of this chapter to the aim and objectives

The Aim of this study is to identify training requirements for UK CT radiographers regarding specifically social, clinical, and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation. This chapter partially met the aim since it measured emotional intelligence a social factor in the clinical environment.

This chapter met the following objectives:

- using a longitudinal study measure pre- and post-registration radiographers' emotional intelligence
- using appropriate methods of analysis compare and contrast data with evidence base
- discuss combine and contrast emerging themes
- document the findings accurately and coherently for dissemination.

Chapter 10- Expert opinion

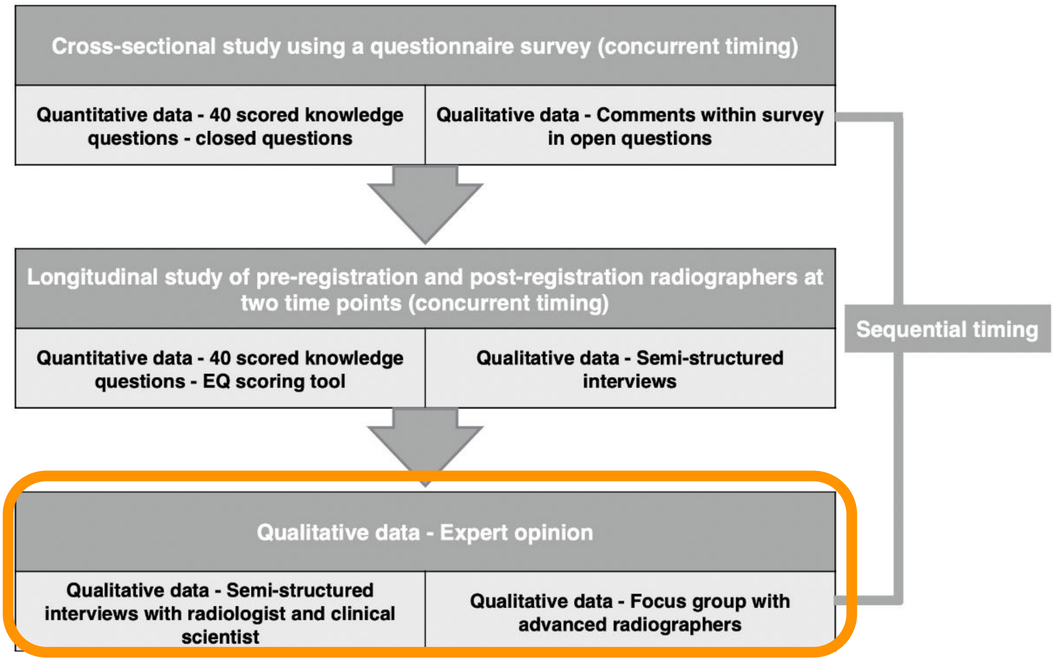

Figure *10.1. Schematic diagram of the research design- phase3 triangulation of data*

This component of the research involves a focus group with radiographers exploring four main themes, identified from data acquired from the previous phases of this study. The themes are: CT patient dose optimisation, training and education, collaborative working, culture of the clinical environment. Dose optimisation is achieved at a local level through active promotion and cooperation between professional groups, therefore radiologists and

clinical scientist's opinions were sought via individual interviews. The individual expert interviews will determine the approach to dose optimisation in more depth. The questions were formulated from the themes identified in the focus groups and from the overarching scaffolding identified in this study. The focus group and individual interviews provide saturation of the previous qualitative phases of this study.

10.1 Background

Qualitative research has become more popular since it is important to exam the feelings, experiences, and beliefs of groups of people to gain a holistic overview in research. Qualitative studies normally have smaller sample sizes than quantitative research, but in qualitative research more data does not always mean more information as the study progresses, since even one occurrence of a theme can assist with understanding the topic because a qualitative study is concerned with meaning (Mason 2010). Analysis in qualitative data is very time consuming, often requiring teams of people to analyse the data which can be impractical for PhD lone researchers (Mason 2010).

Qualitative research is now recognised as an accepted form of research in publications. Research reviewers are interested in the assessment of quality within qualitative research to make sure there is rigour, credibility, and relevance (Kitto et al., 2008). Verification is required in qualitative studies because it could be argued that qualitative data analysis is more subjective than quantitative data analysis (Burnard et al., 2008). Triangulation is a way to enhance interpretative rigour to improve the validity and reliability of a qualitative study by comparing the results of two or more sources of data (May and Pope, 2000; Kitto et al., 2008). Verification is required in qualitative studies because it could be argued that qualitative data analysis is more subjective than quantitative data analysis (Burnard et al., 2008). Triangulation is a way to enhance interpretative rigour to improve the validity and reliability of a qualitative study by comparing the results of two or more sources of data (May and Pope, 2000; Kitto et al., 2008). Triangulation is present in this study by the collection of qualitative and quantitative data but if was felt that further saturation would be useful to add validity and relevance to the research.

Morse (2015) describes saturation as developing data within the process of inquiry, then joining scope and replication, to develop the theoretical aspects of inquiry. Scope is defined as the comprehensiveness of the data and refers to the depth of the data and not necessarily the amount of data, making sure all avenues are explored. Scope is provided in this study by recruiting three professional groups, radiographers, clinical scientists, and radiologists as well as following pre-to post-registration radiographers in the longitudinal study. Replication is defined as data from different sets of participants that have common characteristics (Morse, 2015), replication is provided in this study by the three phases. This study includes data from the national survey, the longitudinal study and triangulation is provided by the focus group and expert interviews. Fusch and Ness (2015) point out that one size does not fit all, and that the depth of data is the important concept. The data collected in the study should be sufficient to answer the research question, but this is a moving target, and it is difficult to say whether a qualitative study really reaches saturation (Lowe et al., 2018). There are several published methods to check for thematic saturation Lowe et al. (2018) have produced a statistical saturation index. Hancock et al. (2016) explain that displaying data in a visual manner can lead to greater transparency of data. The Lowe et al. (2018) statistical saturation method is making statistical calculations from qualitative data, and it was felt that it would not be appropriate for the data collected in this study. This phase of the study will explore the themes identified in the first two phases of the study to provide saturation. Visual saturation of the themes has been produced to indicate saturation across the three phases and will be presented at the end of this chapter (Hancock et al., 2016).

10.2 Method

This is a qualitative study which links to the two previous phases, a cross-sectional survey and a longitudinal study. The overall PhD research uses sequential mixed methods consisting of three linked convergent parallel methods, integrating, and connecting quantitative and qualitative data. The parallel mixed methods with concurrent timing, acquiring both sets of data at the same time in a single study (Johnson et al., 2007).

Quantitative and qualitative data were treated independently during data collection and analysis, the results were combined to provide breadth and depth of understanding to inform the next stage and the strands were used to triangulate themes (Tashakkori & Teddlie 2021). The resultant synthesis at each stage will mix and merge results from the strands to give an overall interpretation, the final synthesis will use elements from all three stages (Tashakkori & Teddlie 2021).

Since this phase of the research is seeking data saturation within a qualitative methodology, the number of participants and the number of focus groups/ interviews were dependent on data triangulation being achieved. Individual interviews of other professional groups were formulated from themes identified from the longitudinal study and the focus group. Purposeful recruitment was used to recruit participants.

Consent was sought and granted from the independent healthcare site CEO where the participants were employed. Purposeful sampling was used for convenience, no coercion of any type will not be used in this study.

10.3 Participants

The radiographers recruited to join the focus group were advanced CT radiographers. Health Education England (HEE) defined the term ‘advanced clinical practice’ in 2017 (Society of Radiographers 2020b).

Advanced clinical practitioners have a considerable depth and breadth of radiographic practice, equating to the definition of advanced CT radiographers in the focus group. There are 4 pillars of advanced clinical practice being: expert clinical practice, education, leadership and management and research (Society of Radiographers 2020b). Advanced CT radiographers were defined as working in CT scanning for at least five years, having a considerable depth and breadth of CT practice, competent of a variety of CT imaging techniques and responsible for training others in CT scanning. Advanced CT radiographers have participated in advanced CT training and competency and are able to run and lead the CT department as the manager or in the absence of the manager. Advanced CT radiographers work with multi-disciplinary teams. The advanced CT radiographers were all from one centre but had experience as advanced CT radiographers in at least one other centre and had worked as radiographers in at least two other centres and had been qualified from 10-20 years. Being radiographers, all were HCPC registered.

The clinical scientist who participated in the interview was an HCPC registered clinical scientist and recognised as a Medical Physics Expert (MPE).

The radiologist recruited for the interview was a General Medical Council (GMC) registered consultant radiologist.

10.4 Modification of focus groups and interviews due to COVID-19 pandemic

Approval was granted from the UH ethics committee in 2019 for this phase of the study (HSK/PGR/UH/03774). The COVID-19 pandemic in March 2020 meant that face-to face interviews and focus groups were not allowed under UK government restrictions. The original ethics approval was granted until June 30th, 2020, but all UH ethics applications were given a blanket extension for as long as suspension due to pandemic, therefore until December 30th, 2020. The ethics committee were asked to confirm that the suspension rules applied to this study before recruitment was started and the ethics committee replied to say that the suspension rules did apply. The ethics committee would not allow face-to-face interviews and stipulated that all interviews/focus groups should move to a virtual platform. The participant information sheets (PIS) were rewritten to accommodate the move to the virtual environment. PIS were emailed to the potential participants and a consent form was sent via email if they wished to be recruited into the study. The consent forms were signed and then returned by email.

It would have been difficult to undertake virtual focus group six months earlier due to the pressure of staff who were working in the clinical environment in a pandemic. At the time it was frowned upon to approach clinical staff working in a pandemic and hence the six-month suspension by the ethics committee. The increased workload and working behind PPE masks and visors under a prolonged business continuity plan had its toll on the staff. By the end of 2020 participants had the experience of working in a virtual environment and were familiar with the technical challenges (Johnson and Odhner, 2021).

For face-to-face focus groups six to ten participants were required but in virtual environment four to five preferred to get better interactions online (UXalliance, 2020). When conducting a focus group online it can be difficult for participants to be familiar with each other and to develop a balanced discussion, the recruited advanced radiographers worked together so they could participate in an open discussion and challenge each other if required (Gill and Baillie, 2018). The participants were recruited via email, since meetings were not allowed at this time. For the focus group, the advanced radiographers had to agree on a time that was convent to all, and they decided to join from their homes early evening. All participants were aware that they needed to join from a location where they could be alone, undisturbed with the technical ability to join via their computer systems (Johnson and Odhner, 2021). The focus group was arranged in lockdown because people were not participating in activities the evening for themselves or children and therefore had more time to participate. Members of staff who had had experience of CT in different settings and centres, with over ten years' recent experience in CT scanning were targeted for recruitment since they had broad experience.

Microsoft Teams was chosen as the virtual web platform because members of the focus group were familiar with using it for work and it did not cut off after a certain time which some other platforms did. Video recording not done since the ethics application was for audio recording only and it was felt that the recording should remain within the parameters of the ethical approval. Advanced techniques such as screen share, virtual post-it notes were available on this platform, but it was decided to keep it simple.

Subject areas have been formulated from thematic analysis of the qualitative questions from the two previous phases which were a cross-sectional survey and a longitudinal study. Four main themes were identified, which were: CT patient dose optimisation, training and education, collaborative working, the culture of the clinical environment. An extra question was asked about the impact of COVID-19 since it was felt that this was relevant for the time.

Careful preparation was key, a schedule for the meeting was written to make sure the group could have an open discussion. There was an introduction script, welcoming participants, setting ground rules, and outlining themes (Gill and Baillie, 2018). Everybody joined and there was time to welcome members as they arrived and encouraged them to chat before the formal part of the focus group, this was also an opportunity to check technical factors such as volume. Although for the original face-to-face group a facilitator was planned, due to small numbers and the issues with a remote virtual facilitator it was decided that the researcher would be both observer and facilitator. A note sheet was prepared for each theme so it could be documented easily, the session was recorded via an audio recording App. The recordings were password protected and transferred directly to a password protected computer after the focus group. It was decided to keep the focus group to 45 minutes which is recommended for virtual environment since participants can tire easily (Stewardt and Shamdasani, 2017).

The radiologist and clinical scientist were interviewed via the phone since this made them more flexible with timings and led to less technical issues.

10.5 Findings

The data from the third phase of the study was qualitative data, providing triangulation of data for the qualitative arm of the study. The findings below triangulate the qualitative data from the first and second phases of the study and reinforce the findings of previous phases of this research. Four themes were discussed by the focus group and experts, education, dose optimisation, collaborative working and culture. Collaborative working was included in dose optimisation as a sub-theme to match the longitudinal study. The focus group and expert opinions provided depth to the study allowing a discussion to develop and sometimes offering opposing views.

10.5.1 Education

Table 10.1 - *Frequency table education*

Sub-category	Number*
Undergraduate training	4
On-the-job training (including radiographer & radiologist talks/training)	12
Applications training/talks	14
Postgraduate training	6

*Numbers are individual mentions.

Some of the advanced radiographers said that they had only received training in CT scanning as an undergraduate twenty years ago. At the time it was not an HCPC requirement to be able to undertake head scans post qualification, but the radiographers did spend time on clinical placement gaining experience in CT scanning.

Table 10.2 - *Focus group comments*

"Well, I think my only CT training of how a scanner works was when I was at Uni which was more than 20 years ago." [FC Rad 1]
"*I've had no formal CT training or apps training since then."* [FG Rad 1]

It is important to deliver high quality undergraduate CT training at undergraduate level if this is the only formal training most radiographers receive.

Most CT training seems to be delivered as in-house training. Some on-the- job training is practical, and some is delivered by professional experts which has a place in the holistic training of radiographers. Clinical scientists are involved in the in-house training which keeps radiographers up to date with radiation law, radiation dose aspects, exposure parameters, and quality control of the scanner. Clinical scientists can also contribute to audit and research in the department.

Table 10.3 - *Focus group and interview comments*

"*I think also there is probably a place in there for medical physics experts because they have a vast knowledge of different parameters and what different things do.”* [FG Rad 2]
"*I give in-house training but it is (timetabled for) 20 minutes at the end of a 3 hour session, targeted focused lunch time talks would be better, staff would self-select to attend.* “ [Clinical scientist]

Some radiographers felt that their knowledge was limited, but they could contribute to teaching certain aspects.

Table 10.4 - *Focus group comments*

“I would say that I am not great on that scanner and wouldn’t feel confident changing a lot on that scanner but kind of other things like you don’t need to scan that or bring that in a little bit for the FOV.” [FG Rad 3]

It was felt that video clips within the CT scanner, embedded by manufacturers could help with training and keeping up to date after initial training.

Table 10.5 - *Focus group comments*

“*on my previous scanner we had, it wasn’t live training but the scanner had some I don’t know what you call it but it had a folder you could play little clips of how you could do for example how you could setup the CT, like a reminder as if you had videos kind of online booklet and that was helpful but more as a follow up or a reminder.”* [FG Rad 4]

The clinical scientist felt that rotational roles of radiographers helped staff the department and provided a flexible workforce but there could be knowledge gap since they were not specialists in the modality:

“Rotational staff are a solution to a problem but not the same as permanent staff.” [Clinical scientist]

Within the department there will always be radiographers with a wealth of experience and knowledge. This was reinforced by the opinions of the participants in the longitudinal study.

Table 10.6 - *Focus group comments*

"*Some of them do it really well like when you are training there is always good radiographers who help you to learn better”* [FG Rad 1]
“*I think a lot of it is how much the CT team understand and are willing to pass onto you as well.”* [FG Rad 1]

The consultant felt that radiographers are trained well:

“Training wise they get enough to do their job most of the time its fine and actually the mistakes aren’t about radiation they are normally human mistakes like I scanned the wrong patient, I did the wrong type of scan because I read it wrong because I had a bad day.” [Radiologist]

The radiologist felt that there was a two-way exchange of information, which may not seem obvious to radiographers. None of the participants in the previous phases of the study or the focus group felt that knowledge was being transferred between parties, but being delivered to them:

“The problem is that radiologists don't hang out with the people who actually do the scan and that is a problem because we get asked questions, and we practically logistically don’t have a clue.” [Radiologist]
“I very much rely on the experience radiographers to guide me if I am honest.” [Radiologist]

The consultant explained that during the COVID-19 pandemic communication is key and more challenging:

Table 10.7 - *Radiologist comments*

"We're not on the shop floor anymore, you haven't seen me for months." [Radiologist]
"………equally there has been some sort of compensation like the MS Teams meetings we are having at least it has prompted that." [Radiologist]
"Communication is key, I think COVID disrupts the communication pathway somewhat because it is disjointed." [Radiologist]

One of the members of the focus group was currently undertaking a postgraduate CT course, the others had not received postgraduate training. They felt that they had learnt a lot from attending the postgraduate course and the course had helped them think about dose reduction in CT scanning.

Table 10.8 - *Focus group comments*

"It's kind of then not necessary taught me but brought me back to thinking about dose. Whereas I think you can get in the mindset that err just push it and go. Like whereas that has made me rethink again, rethink what I am doing and how I can make it better even without adjusting, just smaller things like reducing my FOV and stuff." [FG Rad 3]

The clinical scientist agreed with this:

"*Radiographers who have attended post graduate courses are more aware of recent innovations, how to scan patients and more dose aware. Can do a literature search to find out, if nothing else."* [Clinical scientist]

This concurs with the experience of the qualified radiographers in the UK national survey who felt that more radiographers needed to attend postgraduate courses since they required the up-to-date knowledge, and they were providing most of the training to student and newly qualified radiographers. In the longitudinal study the participants really appreciated the in-house training opportunities from clinical scientists and knowledgeable radiographers. It is important to provide training opportunities for senior radiographers so the knowledge can be disseminated within the department.

The advanced radiographers participating in the focus group felt that extra knowledge was best provided by application experts, this is because the scanners are becoming more and more technically complicated. Some departments had scanners from several different manufacturers making the challenge of being familiar with technically advanced equipment even harder.

Table 10.9 - *Focus group comments*

" I have worked briefly where we had to go across sites and switch between Siemens and GE and that was quite difficult." [FG Rad 4]
"I have done 2 GEs that had very different platforms but the same make but they looked like one was the VCT and one was completely different." [FG Rad 3]
"*The most I ever learnt was 2 weeks with apps.(application specialist), I mean just probably yeah, the knowledge about the scanner."* [FG Rad 3]
"*I'm sure there could be much more done with the dual energy, I don't really know anything about it."* [FG Rad 2]
"*It feels like there is a gap of my knowledge that lost really which is a real shame."* [FG Rad 4]
"*With the Apps specialist I could devise protocols, I could do dose reduction, setting it all up."* [FG Rad 4]
"*I think the apps specialists have a wealth of knowledge like ... said they come in and teach you how to adjust things um I think they should come in more often."* [FG Rad 2]

Unfortunately, application specialists are employed by the manufacturers and therefore departments do not have a say in how much time they have with them. Some scanners are towards or past the end of their recommended life (Care Quality Commission, 2020), and therefore the last time the department saw an application specialist could be when the scanner was installed or when major software updates have been installed which could have been years ago. Some contracts with manufacturers do have more visits from application specialists and most manufacturers do have annual meetings to discuss applications. Most departments would ask an application specialist to assist with setting up new applications such as cardiac scans or dual energy scanning and this works best when radiologists, radiographers and clinical scientists are all collectively involved (Chell, 2016). Both the participants of the UK national survey and the longitudinal study felt that an input from application specialists was essential but acknowledged the lack of direct contact with application specialists.

Table 10.10 - *Focus group comments*

"………. my friend was an apps specialist, and she was covering England and Wales and it was only a year, they move on so quickly as well, it is not a job that you do for very long I don't think. " [FG Rad 1]

10.5.2 Dose optimisation and collaborative working

An understanding of exposure parameters and technical factors as well as a basic grounding in the theory of CT leads to effective dose optimisation in practice. The previous two phases of this study have indicated that radiographers feel that they require further training in dose optimisation and up-to date training in technical parameters for the specific scanner they use. Small changes to exposure parameters can cause a vast change in radiation exposure without the operator been aware in some circumstances (Care Quality Commission, 2013; Elliott, 2014). Inter-professional working is required to achieve effective dose optimisation (Chell, 2016).

Table 10.11 - *Frequency table dose optimisation and collaborative working*

Sub-category	**Number***
Exposure parameters not adjusted	13
Reduce exposure	8
Field of View (FOV)	5
Justify exposure	1
Metallic implants/recons	1
Collaborative working	9

*Numbers are individual mentions.

The advanced radiographers were asked to consider their experience of their previous roles and had many examples of when exposure parameters were not adjusted:

Table10.12 - *Focus group comments*

"*(Paediatric) CT head, used the CT adult protocols for many years until 2010. Can't remember why we changed them. I don't know who came along and said what, I don't know why we changed it certainly wasn't to do with a radiologist. It may have been local MPE."* [FG Rad 2]
"*I certainly have never changed anything for each individual patient unless the scanner tells you to."* [FG Rad 1]

Some members of the focus group had experience of exposure parameters being adjusted to reduce exposure:

Table 10.13 - *Focus group comments*

"*We had a really good cardiac radiologist for every patient he would go in and look at them and then decide what kV you would give them. Like he was really hot on making sure everybody had the lowest kV if possible."* [FG Rad 3]

"*So they only had kV not mA?" "That's a bit like we used to do with …….when he didn't want contrast and we used to change the reference mA"* [FG Rad 1]
"*I think the more technical the scanners have got the less we are encouraged to change anything."* [FG Rad 4]

One participant disagreed:

"*in my previous job the radiologists would just be quite happy with the images that we gave them and they would not be interested in trying to help us optimise any protocols, I don't know if it was because they din't care or they didn't know how to do it or just it wasn't the done thing. ………… now I'm involved in dose optimisation, so we did actually change things and optimise the dose for (*anon). A radiologist wanted to help."* [FG Rad 2]

The participant radiologist pointed out that:

"We know that increased radiation dose is bad, but we don't know at what point how much and how exactly it works." [Radiologist]

The focus group participants agreed that protocols would be changed for smaller patients:

Table 10.14 - *Focus group comments*

"*If they were smaller/younger we used to adjust the doses and smaller scan parameters."* [FC Rad 4]
"We had a trauma protocol for very small patient, I can't remember how we used to use it if they were smaller/younger we used to adjust the doses and smaller scan parameters but that is the only one I can think of." [FG Rad 3]

Two of the advanced radiographers had been involved in dose optimisation projects, one with young cancer patients who are sequentially scanned in follow up for many years, and one scanning a specific area.

Table 10.15 - *Focus group comments*

"*I think (MPE) is quite keen to reduce the doses as much as we can and so they choose to use the young cancer scans because they can be a bit noisier but still be of decent quality so we spent quite a lot of time in reducing the kV in stages and then we got so low that it was too noisy. "* [FG Rad 1]
"*It's quite a lot of work but it is worth it. I think there was a 40% dose reduction in the end, its massive."* [FG Rad 1]
"*Certainly when I did the area specific scans, I did dropping the mA and then (radiologist) got to look at the images to report back and try and get hold of MPE to discuss with him as well."* [FG Rad 2]
"*It took at least 6 months."* [FG Rad 2]

The focus group felt that the COVID-19 had influenced the dose optimisation process:

"*I think certain people are just doing other things or their priorities have changed so there isn't necessarily the time available at the minute to do that kind of thing over 6 months."* [FG Rad 1]

The radiographers in the focus group were aware that radiation dose could be lowered in some cases by careful demarcation of the FOV required.

Table 10.16 - *Focus group comments*

"*For CTPAs we never really scanned further than to the top of the apices to the bases, like never just because they say if they are that peripheral they are not that significant. That obviously cut out a bit of dose.*" [FG Rad 3]
"*We did it for PAs and for IVUs starting at the bottom for the bladder and as soon as you got kidneys you would stop.*" [FG Rad 1]
"Yes, (with specific area scans) that got reduced as well because that was a clinical decision with (radiologist) and surgeons, well they decided actually they said we don't know why you scan up so high we don't need that information so finally we reduced the FOV." [FG Rad 2]

Reducing the FOV as much as possible when possible is a dose reduction theme that the participants in the longitudinal study mentioned as an easy way of reducing dose if relevant anatomy was not missed by the reduction.

The clinical scientist explained that:

"The shape of the person is more important than the weight, a person weighing 90kg could be twice the volume of another person weighing the same." [Clinical scientist]
"Manufacturer's recommendations were used as base line; the clinician needs to decide if the dose to patient is producing acceptable image quality. Always get sign off from clinician." [Clinical scientist]

The consultant agreed that sign off on image quality was important:

"You have got the radiologist for the clinical side to say what is appropriate and what's not. You have radiographer saying logistically this is what we can and can't do, within our remit and this is our capacity etc etc and then you have got the physicist saying oh you haven't touched on this regulation you need to look at that." [Radiologist]

The consultant mentioned justification, this is not surprising since it is the practitioners' role in IR(ME)R (The Ionising Radiation (Medical Exposure) Regulations 2017) [1322]). They gave an example of where they needed to discuss the justification with patients:

"*I rarely have to have conversations with patients about dose, only pregnant ones. Then I tell them ………………….. and they say okay. They often ask when the last time was when you did one of these on a pregnant woman. This is a theoretical risk and I have to tell you about it. It not really a huge problem.*" [Radiologist]

Reconstruction of the images to reduce dose or increase image quality was mentioned by the radiographers but even though the scanners are capable of reconstructing images to remove metallic artefacts or smooth the images, these technical reconstructions are not used regularly.

"*…………….. when we dropped the mA it became a bit noisy, we increased the (reconstruction) value to smooth the image.*" [FG Rad 1]

Justification was mentioned by students and then as qualified radiographers but when radiographers have been working clinically in CT for a long time, they will authorise CT scans under protocol as operators but are unlikely to take on a practitioner role unless they have received postgraduate training, and this would normally only be in their specialised area (Care Quality Commission, 2020). This would mean that for most request forms they authorise the process of justification has already occurred e.g., would U/S or MRI be a demonstrate this pathology without the requirement for ionising radiation. Radiographers should not forget that at any point in the referral process they can query the need for a CT scan with a radiologist.

As advanced radiographers the focus group members had had experience of collaborative working. They were all impressed with application specialists, and all felt that extra training from application specialists would be a great help in understanding the technical aspects of the scanners as well as how to achieve dose optimisation.

The focus group participants also had experience with working with radiologists and clinical scientists.

Table 10.17 - *Focus group comments*

"When I worked at …. they would come in every couple of months and sit with us for an afternoon and that was very helpful. We would ask them questions they were the ones to answer questions and offer suggestions, that was quite helpful but that was unusual. It was the only time I have come across it in about 20 years." [FG Rad 4]
"Interestingly I was in the same Trust at the same time and those people never came to our hospital ever. I never saw one. " [FG Rad 1]
"I've seen CT physicists before in other jobs, but they never had any kind of collaboration with us to reduce doses not like (the present MPE) does." [FG Rad 1]
"……. where I used to work (MPE) was very good and they used to have those meetings and they were very good, any changes to imaging they would be involved in whether it was an X-ray room or a CT scanner and all protocols for anything that was happening. They were always involved in it." [FG Rad 1]

The participants thought that reciprocal learning could be a benefit to both parties:

Table 10.18 - *Focus group comments*

"Maybe some (of the MPEs') trainees could come down, it would be good practice for them as well as us." [FG Rad 2]
"That's a good idea for them to come down for them to learn from us and us to learn from them" [FG Rad 4]

The clinical scientist also taught that contacting the application specialist was a good place to start:

"Always contact apps in first instance, normally they have pre-set defaults. Change for research but you can get out of practice if nothing is changed for a long time. All apps (application) people and engineers in UK are good." [Clinical scientist]

10.5.3 Culture

Members of the focus group were a bit hesitant to talk about culture in the department, this was obvious from body language and the fact the flow of the discussion stopped. As the facilitator of the group, I explained that the discussion was about their general opinion of culture in the CT department drawing from previous experiences. The group then relaxed a bit and spoke about their experiences.

All agreed that teamwork was important, with the superintendent running the team and being a permanent member of staff in the department, with rotational radiographers joining and leaving the team daily. They also felt that role of the advanced radiographic assistant dedicated to CT scanning was pivotal in a busy department.

Table 10.19- *Focus group comments*

"*Probably have your 'super 'then the rest would just be different people each day."* [FG Rad 2]
"Usually the common ground is the ARA(Advanced Radiographic Assistant)" [FG Rad 1]
"*I have worked with ARAs like that before and it is lifesaving. We really utilised their full capacity. They were organising the list, cannulating, got patients positioned and on and off the scanner."* [FG Rad 4]
"*There was one who just did CT and if he was off you would have no replacement and he half run the show."* [FG Rad 1]

Most CT control rooms are very small, but the radiographers felt that this enhanced the team and working environment and was not a negative aspect of the design. The control room houses the CT team, and its size restricts other people disrupting the team dynamics as well as people interrupting and therefore causing errors when setting up the scan for the patient.

Table 10.20 - *Focus group comments*

"*Better to have a smaller environment , if bigger you get too many people coming in. They just sit down.* " [FG Rad 1]
"………. we had a 'super 'he was brutal really only people who needed to be in the room were in the room, if anybody had gloves on, they were sent out. He would just chuck people out who shouldn't be in there which was good." [FG Rad 1]
"*I think in a smaller space you need to be tough about it, you need control."* [FG Rad 4]

Having a highly knit team helps with several aspects of the role, the radiologist concurred that:

> *"The key to an efficient working environment is organisation, clear role definition and good communication"* [Radiologist]

The clinical scientist agreed with this opinion:

> *"There needs to be power and authority to move forward."* [Clinical scientist]

The radiologist was aware of different types of people working in the scanning environment:

> *"There are going to be less competent people we are going to have to work wit, we just have to accept that they are less competent, and we are going to have to hold their hand a lot more. We just need to adapt and that is the key of good management that you recognise that you need."* [Radiologist]

The clinical scientist agreed:

> *"Inclusivity is required to help people to grow, more people then develop themselves. CT is not just a tick box exercise. Sharing knowledge empowers people. Some have grown in role so more competent and good for the organisation."* [Clinical scientist]

One radiographer explained how the radiologists in private hospitals wanted to work unquestioned and were not open to dose reduction, whereas the same radiologists in NHS hospitals acted in different ways. This meant that the radiographers working in private hospitals had negative interactions with the radiologists akin to the student/ radiologist interactions in the first part of the longitudinal study. This is a display of power with 'parent' 'child' dynamics and in the end is not a benefit to patients since staff may be afraid to call out radiologists if they feel they are scanning in an inappropriate way (Booth and manning, 2006). Collaborative working using everybody's expert skills and listening to everybody's opinions is a better way forward.

> "*I think when I worked in the private sector there was definitely a culture of no matter what the radiologist said went. They were very anti dose reduction; it was very hard to battle against scanning that sort of thing. It was very much that you were a radiographer, and you didn't have voice. It was quite difficult."* [FG Rad 4]

10.6 Frequency charts

10.6.1 Education

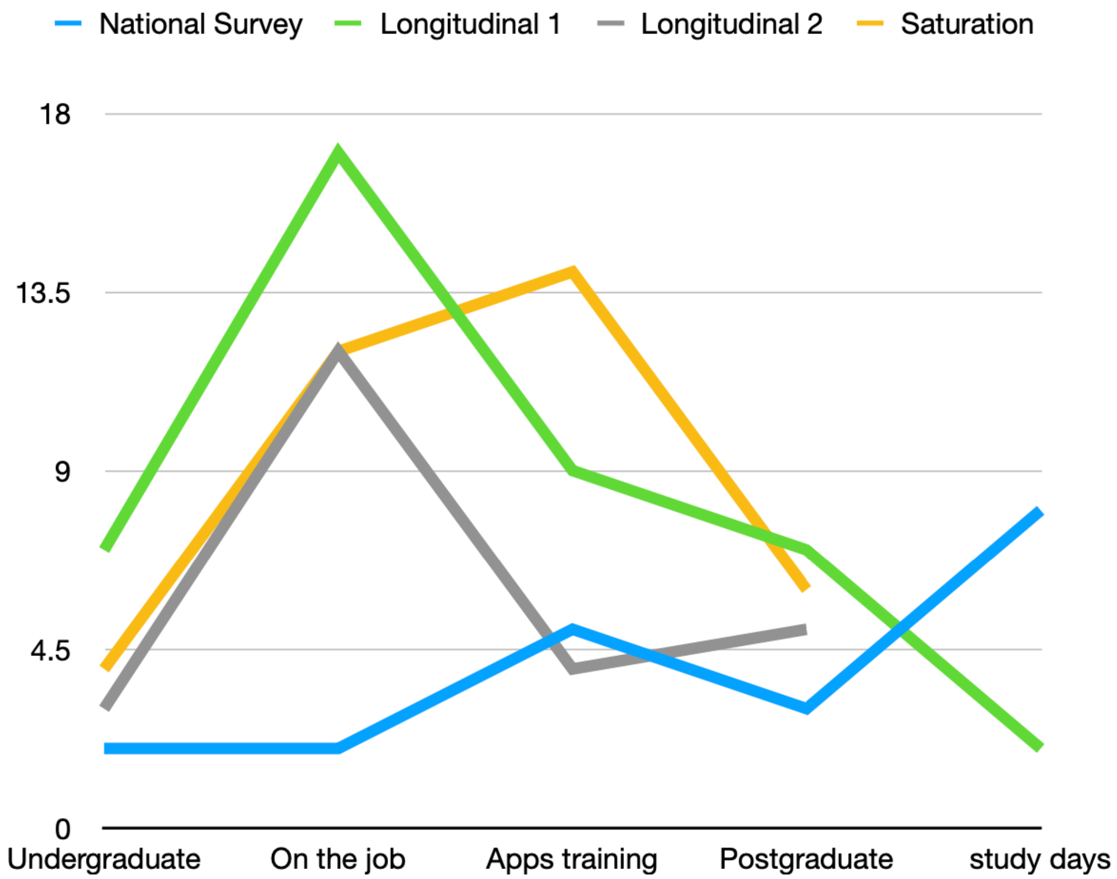

Figure 10.2 - *Frequency chart - Education sub-theme*

This frequency chart shows that there were common sub-themes in the theme of education reported by all phases of the study. Study days were not specifically mentioned in the longitudinal 2 study or in saturation but instead they were included as in-house training by experts such as clinical scientists or other peer groups. The national survey data were collected five years prior to the focus group and expert opinion data so in this time there may have been less attendance at study days due to the financial constraints of departments and the lack of staff. More recently from 2020, prompted by the pandemic, there has been online study days and conferences but no face-to-face sessions since it is felt that training events could lead to the spread of COVID-19.

10.6.2 Dose optimisation

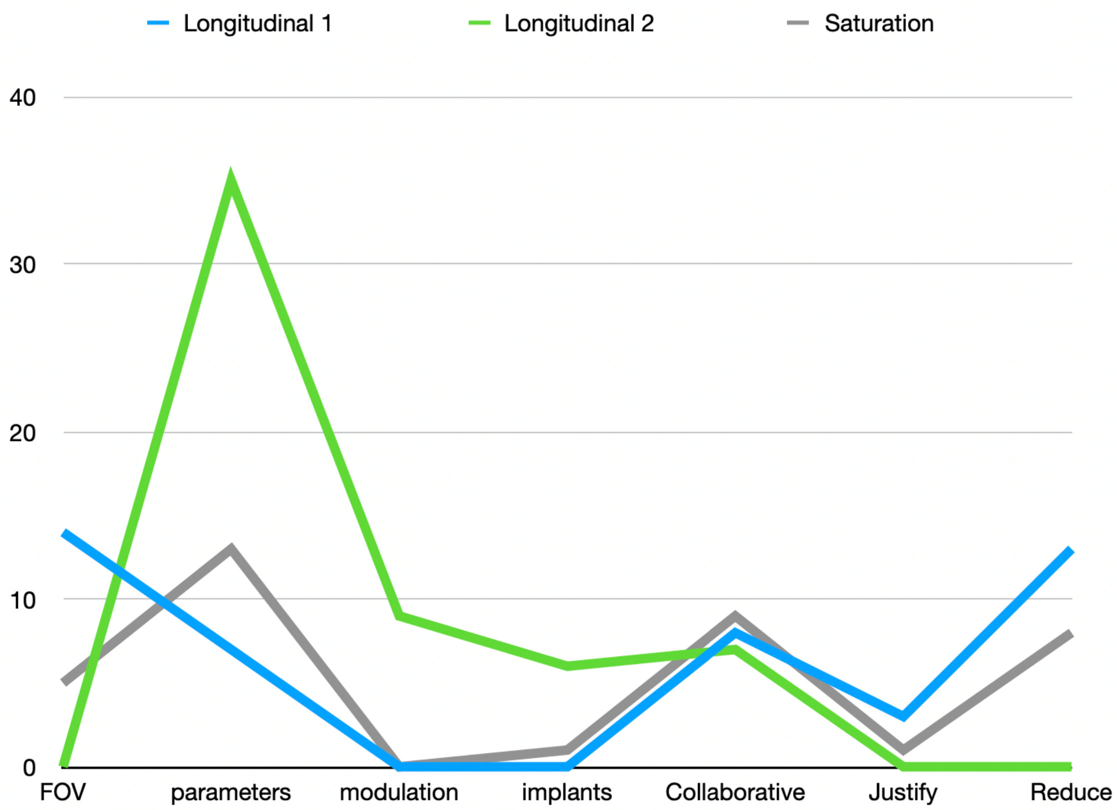

Figure *10. 3* **-** *Frequency chart - Dose optimisation sub-theme*

The national survey attracted qualitative comments about education and qualitative data were not collected about dose optimisation. The two parts of the longitudinal study showed that all the sub-themes were discussed. The FOV was not mentioned in longitudinal 2, dose modulation and metallic implants were only mentioned in longitudinal 2 and justification and dose reduction were not mentioned.

10.7 Discussion

CT specific postgraduate education seems to be rare; most employers feel that CT training is included as a core subject at undergraduate level. In the national survey a quarter of the radiographers had a postgraduate qualification in CT scanning and in the focus group, one of the four radiographers was currently attending a postgraduate CT course. Sloane and Miller (2017) indicate that the attendance on a postgraduate CT course could be rarer than a quarter of qualified staff. Almost a third of the radiographers who completed the UK national survey had been qualified for over twelve years which would be prior to 2003, 8 and 16 slice scanners were available form 2002, they would have been new technology at the time and would not have been installed in most hospitals (ImPact, 2013). Dual Energy scanners have been commercially available since 2006 and cardiac CT scans were made possible from 2008 with the new generation 640 slice multi-slice detectors (International Society for Computed Tomography, 2016). CT scanning is such an advancing technology that up-to-date training is paramount and relying on undergraduate training is not sufficient. The undergraduate curriculum is becoming more crowded with specialist modalities and other cross-sectional imaging techniques meaning that it is unlikely that more time is available for teaching CT scanning. Some universities now have CT scanners and CT simulators which improves the learning experience of student radiographers. In the clinical environment students have a varied experience in this busy modality, some of which is not positive (Hyde, 2015). Sloane and Miller (2017) explain that imaging departments are aware of the issues of student radiographers not being able to gain quality training in cross-sectional imaging and some have introduced preceptorship programmes for radiographers' post-registration. Most of the post-registration radiographers in the longitudinal study had participated in a preceptorship programme, but the programmes varied greatly and only educated the radiographers to a standard to be able to perform CT scans out of hours while on-call. Several of the post-registration radiographers stated that they were not CT radiographers and therefore did not receive CT radiographers' updates or training. Full CT systems are being added to PET and Gamma Cameras, which demonstrate physiology, to create fused images of the patient's anatomy and physiology. CT training for nuclear medicine radiographers also needs to be considered. Radiographers are capable of advancing knowledge by reading articles critically and postgraduate courses can enable this, this was pointed out by the clinical scientist. Access to literature has been a problem in the past but now all articles are electronic this is not a problem since NHS Trust libraries give access to Athens accounts and the Society of Radiographers and the European Society of Radiology give access to their journals. There may be a case for a Society of Radiographers accredited course in CT scanning similar to the certificate of competence in administering intravenous injections.

The focus group felt that local and external professional experts had a big role to play in education and training. The focus group had experience of clinical scientists working collaboratively to optimise dose along with radiologists, these groups also provided local training which was a recommendation in the response to the COMARE 16th report and involvement of medical physics experts is laid down in law in IR(ME)R 2017 (Chell, 2016; The Ionising Radiation (Medical Exposure) Regulations 2017) [1322]). The post-registration radiographers also had experience of clinical scientists delivering local training concurring with the focus group. Unfortunately, application specialists, longed for by the focus group, are external trainers and there is no requirement in law for them to provide updates. If a scanner is installed or a major software update occurs then an application specialist will provide training for radiographers, clinical scientists, and radiologists. The most senior staff normally have the greatest access to the applications specialist, in the focus group the radiographers had had limited but very comprehensive training from applications specialists. Application specialists are normally radiographers who have been trained by the manufacturer to provide enhanced training, but they are a limited resource and as one of the radiographers pointed out they are normally time limited in the role. Relying on training from application specialists for all CT departments in the country is probably an unrealistic expectation and is unlikely to provide consistent uniform training for all CT radiographers. The focus group radiographers agreed with the post-registration longitudinal study radiographers saying that there were always knowledgeable and approachable radiographers in the department who would teach newly qualified radiographers. The radiographers from the national survey pointed out these radiographers may not have had a postgraduate education in CT scanning and may be teaching outdated or incorrect information. There is a problem expecting radiographers to qualify ready to scan in CT when the undergraduate training and clinical placement experience is patchy and inconsistent (Sloane and Miller, 2017). Most radiology programmes would admit that their students should receive more CT specific education in their working lives.

If effective training in CT is not occurring, then adjustment of exposure parameters and dose optimisation will not happen. The radiographers in the post-registration part of the longitudinal study and the focus group explained how they would adjust exposures for small patient if a preset protocol was available and adjust the FOV as the main processes of dose optimisation. Radiographers were unlikely to adjust exposure due to lack of training and fear of causing vast increases in patient dose due to adjusting factors which then change factors within the scanner system. One radiographer did explain that children's head scan exposure parameters were the same as adults until 2010 concurring with a retrospective cohort study of organ doses to paediatric CT patients in UK hospitals which revealed that it was common to use adult CT exposure parameters for children until 2001 (Kim et al., 2012). Radiation doses from CT scans vary across countries and this is attributable to local choices of exposure parameters, high quality up-to-date training and collaborative working is a key to achieving dose optimisation (Smith-Bindman et al., 2019). Some of the members of the focus group were proactively working with inter-professional groups to reduce the radiation dose for specific groups of people or specific areas being scanned, this hands-on approach is time consuming but a benefit to patients and a learning experience for all involved.

The environment has a bearing on wellbeing in the workplace with the radiographers in this part of the study preferring a small, cozy, environment enabling good team dynamics and allowing for undisturbed working leading to less mistakes. Radiographers feel happier in smaller environments, this helps with positive social interactions and the radiographers feel that they are part of a team leading to job satisfaction and a positive culture (Chipere et al., 2020; Lohikoski et al.,2019). In the post-registration phase of the longitudinal study the radiographer who felt animosity and negativity was working in a very large city hospital. Lohikoski et al. (2019) recognise that a positive workplace culture leads to good patient care as well as job satisfaction and this can help with retention of staff which is vital for patient care (Nightingale, et al., 2021). A positive workplace culture is especially important for newly qualified radiographers, most of the post-registration radiographers in the longitudinal study felt welcomed in their departments and were nurtured and managed to undertake an active role. Even though some post-registration radiographers in the longitudinal study were in very busy roles they felt part of the team and much happier than when they were student radiographers. Some pre-registration radiographers took a passive role in their clinical training in CT and did not feel part of the team and lacked a sense of belonging and could not work as autonomous practitioners, Cushen-Brewster et al. (2021) studied students who were on the temporary HCPC register during the COVID-19 pandemic and they reported feeling members of the team and were actively involved in the department. There is a feeling that students belong to the university and not the department in some places which can stop staff investing in pre-registration radiographers and clinical tutors have an important role to play here.

10.8 Conclusion

It is important to deliver high quality undergraduate CT training at undergraduate level if this is the only formal training most radiographers receive. Radiographers lack equipment specific training from experts and as scanners become more technically advanced it is more important to have regular training from applications specialists and clinical scientists, since a small adjustment in exposure parameters can lead to a vast change in exposure. It is important to provide training opportunities for senior radiographers so the knowledge can be disseminated within the department since most radiographers learn from in-house training.

Collaborative working is important because everybody can contribute with their specialty, leading to effective dose optimisation. Radiologists have a role which can be remote from the department, especially since COVID-19, and departments should be proactively encouraging communication between radiologists and radiographers even if this is via a virtual platform. Learning is shared in both directions although this may not be obvious to radiographers. Dose optimisation is being encouraged and considered even if it is just careful consideration of the FOV. In some instances, dose optimisation is being actively undertaken by inter-professional working with all parties having an equal contribution. Team working is important, and the team requires permanent modality specific core staff to coordinate the service in a safe and effective way. On a day-to-day basis the radiographers take an active role in the modality.

The data from the focus groups and interviews matched the data from the other phases of the study.

10.9 Limitations

Originally the plan was to interview more radiologists, clinical scientists, and radiographers from different geographical locations unfortunately this was not possible in the pandemic. The data provided from the focus group and the interviews showed a link to the data collected from the previous phases of the study and therefore provided triangulation.

10.10 Robustness and external validity of this study

Major, V., Ryan, S., O'Leary, D. CT head scans for final year students- Too great an expectation? Oral presentation, ECR Vienna 2022

10.11 Mapping the content of this chapter to the aim and objectives

The Aim of this study is to identify training requirements for UK CT radiographers regarding specifically social, clinical, and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation. This chapter partially met the aim since it triangulated the findings of the previous chapters.

This chapter met the following objectives:

- using qualitative methods to explore advanced CT radiographers' (focus group), medical physics experts and radiologists (semi-structured interviews) expert opinions
- using appropriate methods of analysis compare and contrast data with evidence base
- discuss combine and contrast emerging themes
- document the findings accurately and coherently for dissemination.

Chapter 11- Discussion and Conclusion

11.1 Introduction

Computed Tomography (CT) has a high radiation dose which has a disproportionate amount of radiation compared to projectional X-rays (Joyce, 2020). Major trauma requires CT scans (sometimes in multiple areas) to assess and manage the patient's condition; the benefit therefore will always outweigh the risk of the radiation from the scan. However, for most people, their condition is less severe, and the risk to benefit is not so clear cut especially if the person is in a vulnerable group such as a child or a patient with a chronic condition. All CT scans contribute to the person's lifetime attributable risk of cancer (Kwee et al., 2020; Jeukens et al., 2021; Friedlaender et al., 2019). Children are more sensitive to the stochastic effects. A large cumulative dose of radiation especially if the exposure parameters are not adjusted could lead to an increased risk of cancers in children especially leukaemia and brain tumours (Brenner et al., 2012; Lee et al., 2016; Nagayama et al. 2018). For patients with chronic conditions such as oncology patients, are likely to survive longer than in the past due to new treatments such as immunotherapy and therefore the dose should be optimised for every scan attended in their cancer journey (Kwee et al., 2020; Jeukens et al., 2021; Friedlaender et al., 2019).

Fortunately, for each patient, CT exposure parameters can be adjusted to minimise radiation dose while producing a clinically diagnostic scan, so each patient receives the optimal level of radiation (Martin et al., 2016; Demb et al., 2017; Boseley, 2014; Elliott, 2014). Smith-Binden (2019) explains that decisions on how to set the CT exposure parameters are set locally and therefore vary from centre to centre and country to country. CT scanning is technically complex, so a multidisciplinary approach is required to determine the CT exposure parameters (Seeram, 2018; NHS England, 2020; CQC, 2021).

Even with local CT exposure parameters set to optimise radiation dose, the radiographer can still influence the optimal radiation dose to the patient (Joyce et al., 2020). Current knowledge of dose optimisation techniques are essential knowledge for radiographers regardless of the area in which they are working since this is a professional requirement (Foley et al., 2013). The most effective way of reducing ionising radiation dose to individuals is to find an alternative non-ionising radiation technique such as MRI scanning where available, the radiographer or radiologist must therefore justify and authorise the ionising radiation exposure for the CT scan (Joyce et al., 2020; IR(ME)R, 2017 (SI 2017/1322). Additionally, to keep the patients radiation dose ALARP, radiographers must position the patient correctly, select the smallest clinically relevant FOV, use the ATCM or OBTCM and reduce the kVp if appropriate (Olden et al., 2018; Akin-Akintayo et al., 2019; Martin et al., 2016; Demb et al., 2017;Yurt et al., 2019; Botwe et al., 2021; EuroSafe Imaging, 2022). Beyond undergraduate training therefore, continuing professional development is required to ensure that radiographers remain current with these optimisation strategies.

The CQC (2021) are concerned that there is insufficient training of CT radiographers after new authorisation criteria have been introduced and that justification of CT scans by radiographers requires extensive education not available at an undergraduate level. CT is a highly pressured environment, with numbers increasing consistently. CT scans are predicted to increase rapidly, maybe exponentially in the next five years (Tsapaki et al., 2020; Dixon, 2020; NHS England 2020). The modality is however pivotal in the patient pathway especially with new techniques and applications (Yurt et al., 2019). There is an imbalance between supply and demand of CT radiographers worldwide, which is reflected in UK workforce (Nightingale et al., 2021); thus, the environment is set to become even more pressured.

Dose optimisation in CT is complex requiring collaborative working to establish exposure parameters, sequences, and scanning techniques (Kim et al., 2019; Gershan et al., 2021; Abuzaid et al., 2021). The shortage of radiologists and clinical scientists has influenced radiographer role expansion and setting CT parameters to achieve optimal dose optimisation (The Royal College of Radiologists (RCR), 2021; The Institute of Physics and Engineering in Medicine (IPEM), 2018).

Ongoing education is a key requirement in this technically advanced cross-sectional imaging (Sloane and Miller, 2017). Learning in the clinical environment is not easy to analyse or understand since educational, psychosocial, and clinical factors contribute to effective dose optimisation.

11.2 Summary of study

The Aim of the study was to identify training requirements for UK CT radiographers regarding specifically social and educational factors, and whether these have an influence on the longitudinal approach toward CT dose optimisation. The relationships between social and educational factors in the clinical environment are complex and therefore this study required complex methodology to explore in depth, with consideration to triangulation, the training of UK CT radiographers.

This mixed method study consisted of three phases, which linked convergent parallel methods, integrating, and connecting quantitative and qualitative data proceeded by three linked literature reviews.

The mixed method methodology consisted of:

- An exploration of radiographers' knowledge of exposure parameters and view on education using a cross-sectional methodology
- An exploration pre- and post-registration radiographers' knowledge and experience of dose optimisation within CT scanning, emotional intelligence, and the radiographers' educational experience in the clinical environment using a longitudinal study and
- Qualitative methods to explore advanced CT radiographers' (focus group) and medical physics experts and radiologists (semi-structured interviews) expert opinions.

11.3 Summary of findings

Within the first exploration of the topic in a nationwide survey, only 9% of radiographers reported that multi-disciplinary team working was occurring in their departments with 54% of respondents indicating that radiologists alone set the protocols, correlating with the previously published study by Foley et al. (2013). More than a third (34%) of UK radiographers had not seen a change in protocol in the last two years. Reasons for changing protocols were: new scanner, new software, reduce/optimise dose, research protocols and evolving protocols while more than a third (36%) of UK radiographers had concerns about CT dose in their departments, concurring with the Foley et al. (2013) figures of 40% for radiographers.

When the 40 CT parameter questions were scored the overall score was similar to the radiographers in Foley et al. (2013) study with a mean score of 28.1 and 29 respectively. Although 40% of UK radiographers responding to the survey had Postgraduate qualifications, 98% felt that further education within optimisation of CT parameters would be beneficial. Analysis of the UK radiographers' comments by thematic analysis identified education as the main theme with five sub-themes. The sub-themes were: standardised training at undergraduate level; postgraduate training; on-the-job training; CT-focused CPD; manufacturer's training.

There was no consensus, some UK radiographers' felt that specialist education for CT scanning could be addressed at undergraduate level:

> "It seems the great majority of radiographers learn CT on-the-job rather than in an educational organisation…………………. As radiography develops into specialist areas, I believe undergraduate programmes would reflect the changes in the profession."

Regular continuing CT-focused updates was favoured among respondents, and this was likely the most achievable way of providing mass education and training for radiographers. The participants felt that education would support them with advancing technology, often new systems are commissioned with initial training given but due to staff shortages and the need to reduce waiting lists, all CT staff are unlikely to be timetabled to receive initial application training. This means that on-the-job training occurs which, as pointed out by the respondents, can lead to radiographers who have trained this way, not having enough knowledge to produce optimum exposure parameters.

11.3.1 Systematic review: education

The main findings were that education in the workplace is needed more now than ever due to the complexity of diagnostic imaging (Sloane and Miller, 2017). The main barrier to engaging in education in the imaging department is lack of time; with the increased workload radiographers felt that they needed to protect their 'free time' for relaxing, leaving less time for education outside of their 'work time' (Wareing et al., 2017; Society of Radiographers 2021a).

Students have little opportunity to change exposure parameters on clinical placement, with CT scans predicted to increase 100% in the next five years, there is likely to be an increased demand on clinical placements (Stowe et al., 2020; Nightingale, 2016; Society of Radiographers 2021a). Undergraduate radiographers will be less likely to participate in active learning, finding it difficult to retain information about adjusting exposure parameters based solely on theoretical knowledge without involving critical thinking (McInerney and Baird, 2015). Radiation protection and patient safety is being taught in undergraduate programmes, which is a key part of the radiographer's role (England et al., 2016). Currently most CT skills are being taught in the clinical environment but this training is not producing newly qualified radiographers who are competent or confident in cross-sectional imaging (Sloane and Miller, 2017).

11.3.2 Systematic review: psychosocial factors

There is a consensus of opinion that learning in the clinical environment is complex, involving many factors including learning preferences, emotional intelligence and social skills, with low levels leading to stress and low self-esteem and high-levels leading to academic achievements (Girin et al., 2021; Dungay and Yielder, 2016; Sa et al., 2019).Training in the clinical environment promotes active learning and is a vital part of radiography training courses (Brydges et al., 2020). For successful workplace learning, commitment and interaction is required between trainers and learners (Olmos-Vega et al., 2018). Students with high levels of stress and low self-esteem due to low levels of emotional intelligence and social skills, and lack of familiarity with the specialised environment are unlikely to have a flourishing relationship with their clinical supervisors and effective learning will not occur (Girin et al., 2021; Dungay and Yielder, 2016; Sa et al., 2019; Olmos-Vega et al., 2018). Clinical reasoning and critical thinking seem to be lacking in regard to CT dose optimisation in the clinical environment (McInerney and Baird, 2015).

11.3.3 Longitudinal study: Quantitative data

The quantitative data were acquired by the pre- and post-registration radiographers completing the CT exposure parameter questionnaires (Foley et al., 2013 (Appendix 1)) and the emotional intelligence questionnaire (Petrides, 2009 (Appendix 2)) as well as factual questions.

After two years as registered radiographers one third of the original participants had not worked in CT scanning. When the 14 participants in the pre-registration group were compared to the 7 participants in the post-registration group, the result demonstrated a significantly higher score in the CT exposure parameter questions post-registration, $t\ (20) = -2.93$, $p=0.0085$. When the 47 participants in the UK radiographer group were compared to the 7 participants in the post-registration group there was no significant differences in the scores of the CT exposure parameter questions, $t\ (43) = -0.49$, $p= 0.627$. Over time the post-registration radiographers have gained more knowledge of CT exposure parameters which is desirable.

The global emotional intelligence scores showed no significant difference pre-and post-registration but when separate categories are compared, the results for wellbeing and emotionality are significant (p=0.039 and 0.047 respectively).

11.3.4 Longitudinal study: Qualitative data

Three themes were identified: Education, Culture, and Dose optimisation pre- and post-registration comments from the three themes respectively are shown:

"…if you get stuck doing one thing one way, you think it is the only way to do this thing" UG14
"We have a structured training, going to CT in the afternoon" *PG10*
"Students just helping patients getting on and off table – hard to learn anything." UG3
"From the first day we are involved in everything" *PG10*
"Would like to have had protocols explanation of why they change" UG4
"Its an advantage that the people who actually know these things can do the teaching sessions" *PG4*

The pre- and post-radiographers appreciated the need to adjust exposures for children being scanned although they may not have seen the adjustments in practice at this stage of their careers so they were aware that they may need to ask for help from a senior CT trained member of staff.

The post-registration radiographers seemed to have expanded their knowledge since being in practice and were using the automatic dose modulation even when the patient had a metallic implant, and they mentioned the reconstructions which could be used to alleviate the beam hardening artefacts caused by metallic implants.

11.3.5 Expert opinions: qualitative data

The findings triangulate the qualitative data from the first and second phases of the study and reinforce the findings of previous phases of this research. Four themes were discussed by the focus group and experts, education, dose optimisation, collaborative working and culture. Collaborative working was included in dose optimisation as a sub-theme to match the longitudinal study. The focus group and expert opinions provided depth to the study allowing a discussion to develop and sometimes offering opposing views.

Most CT training seems to be delivered as in-house training. Some on-the-job training is practical, and some is delivered by professional experts, having a place in the holistic training of radiographers. Clinical scientists are involved in the in-house training which keeps radiographers up to date with radiation law, radiation dose aspects, exposure parameters, and quality control of the scanner:

"*I think also there is probably a place in there for medical physics experts because they have a vast knowledge of different parameters and what different things do."* [FG Rad 2]
" *I give in-house training but it is (timetabled for) 20 minutes at the end of a 3 hour session, targeted focused lunch time talks would be better, staff would self-select to attend.* " [Clinical scientist]

Some radiographers felt that their knowledge was limited, but they could contribute to teaching certain aspects:

"I would say that I am not great on that scanner and wouldn't't feel confident changing a lot on that scanner but kind of other. Things like you don't need to scan that or bring that in a little bit for the FOV." [FG Rad 3]

All agreed that teamwork was important, with the superintendent running the team and being a permanent member of staff in the department, with rotational radiographers joining and leaving the team on a daily basis. They also felt that role of the radiographic assistant was pivotal in a busy department.

11.4 Discussion of findings

At every phase of this study radiographers felt that they required more training as the technology evolved. Radiographers irrespective of experience were still waiting to be updated on how to adjust exposure parameters on modern scanners. Collaborative working between radiographers, radiologists, medical physics experts and applications specialists could achieve patient specific dose optimisation. Due to lack of time and a shortage within all staff groups, this process was not actively occurring in departments although where possible limited collaborative working was occurring.

Although UK radiographers felt that CT scanning should be taught thoroughly at undergraduate level; they did not comment that undergraduate training would become outdated within a short period of time due to rapid technology advancement in CT that few higher education institutions could sustain. Over half the participants (55%) had been qualified six years or more, starting their training nine years previously, the massive advances in technology could mean that only current undergraduate training would be up-to-date for a minimal period of time.

The undergraduate curriculum with integrated clinical practice over three years is a good model of education, diagnostic radiography however has become more complex and is delivered in a constantly changing busy environment (Westbrook, 2017). It is hard to learn clinical skills in cross-sectional modalities, especially in the pressurised CT department.

The pre-registration radiographers were aware of the requirement to optimise dose, but some lacked experience to know what to do in practice with many not ever being allowed to change parameters under direct supervision. This led to a lack of understanding of the dose reduction including reducing the kVp and using the ATCM correctly which is especially important for vulnerable groups.

Most of the participants felt that on-the-job training was the best way to receive training and education in CT scanning. The pre-registration radiographers did not express any reservations about on-the-job training despite the UK radiographers in the cross-sectional survey expressing that there was a definite knowledge gap. Technology could aid learning, with dose management software packages and CT simulation providing ways of manipulating exposure parameters without using radiation.

One of the reasons on-the-job training can be sub optimum is that there is an assumption that if healthcare professionals are experts in their field that they can teach, but for effective clinical teaching, expertise alone is not sufficient and formal training is required (Spencer, 2010). Another reason is that in a busy department radiographers, who have participated in formal training, are forced to give brief and often less optimum teaching (King et al., 2020).

Some participants mentioned the culture of the clinical placement from a student's perspective. Several students adopted a passive role in the department which had an impact on their training and skill set. The fast paced, highly technical environment of CT scanning meant it was a challenging learning modality as a student. Most departments have acknowledged this and have developed extensive preceptorship programmes for newly qualified staff to enable them to obtain the skill set required for CT scanning. Some students felt supported in CT during their training while others felt they were being used as an extra helper. Over the two years the radiographers' wellbeing and emotionality had increased giving them more confidence to commit to an active role within the department.

The HCPC have a requirement for radiographers to perform non-contrast CT head scans as a graduate attribute. The pre-registration radiographers were not prepared to work as autonomous practitioners especially due to the length of time taken for radiographers to begin working in CT scanning after qualification; over a third of the participants in the longitudinal study had not worked in CT scanning two years after qualification. Currently most CT skills are being taught in the clinical environment, but this training is not producing newly qualified radiographers who are competent in cross-sectional imaging (Sloane and Miller, 2017, Westbrook,2017). The post-registration radiographers in the longitudinal study, were working in non-contrast CT most had received an induction before taking on the role, most with minimal additional training.

CPD was provided within the departments, the radiographers however preferred on-the-job training. Since most qualified radiographers do not have postgraduate education in CT scanning their knowledge can become outdated so in-house training should be supplemented with academic/technical education. There was a culture of nurture, but negativity still existed in some departments.

An important aspect of learning in the clinical environment is psychological safety (Edmondson & Lei, 2014). A positive workplace culture is especially important for newly qualified radiographers. Most of the post-registration radiographers in the longitudinal study felt welcomed in their departments, were nurtured, and managed to undertake an active role feeling part of the team and much happier than when they were student radiographers. Teaching and learning in the clinical environment can be challenging because of the balance between emotions of self, patients, and teacher/learner with all their complications (Mosca, 2019).

Some post-registration radiographers were still unaware how to change exposure parameters in practice and some lacked the background knowledge from the results of the exposure parameter questionnaire. Overall, the post-registration radiographers' knowledge had increased from when they were students. Most of the post-registration radiographers in the longitudinal study had participated in a preceptorship programme. The programmes varied greatly and only educated the post-registration radiographers to a standard to be able to perform CT scans out of hours while on-call.

CT-specific postgraduate education seems to be rare; most employers feel that CT training is included as a core subject at undergraduate level. The focus group felt that local and external professional experts had a big role to play in education and training. The focus group had experience of clinical scientists working collaboratively to optimise dose along with radiologists. Post-registration radiographers had experience of clinical scientists delivering local training concurring with the focus group.

11.5 Conclusion

Radiographers' CT training is unable to keep up with the rapidly advancing technology of modern CT scans. Current knowledge of dose optimisation techniques are essential knowledge for radiographers (Foley et al., 2013). Radiographers taught their CT skills at undergraduate level can only keep up-to-date participating in regular CT professional education, requiring a multi-disciplinary team approach. Advanced CT radiographers still feel that they require more knowledge and applications training before they can manipulate exposure parameters. This feeling being cascaded through the workforce to pre-registration radiographers. Compounded by ever-increasing scan numbers and lack of staff, radiographers feel that they needed to protect their 'free time' for relaxing and leaving less time for education outside their 'work time' (Wareing et al., 2017; Society of Radiographers 2021a). Some pre-registration and newly qualified radiographers felt poorly supported because trained professionals were too busy to pass on knowledge. Where knowledge was being actively taught, the experts in their field were unlikely to have formal clinical supervision or education training and the training would occur on an ad hoc basis. Currently most CT skills are being taught in the clinical environment, but this training is not producing newly qualified radiographers who are competent in cross-sectional imaging (Sloane and Miller, 2017).

There are ways to adjust CT exposure parameters to minimise radiation dose while producing a clinically diagnostic scan, so each patient receives the optimal level of radiation (Martin et al., 2016; Demb et al., 2017; Boseley, 2014; Elliott, 2014). Radiographers have to be empowered to operate the technically complex equipment whilst undergoing the challenge of the balance between emotions of self, patients and teacher/learner with all their complications (Mosca, 2019). The COVID-19 pandemic has added another layer of barriers to learning along with influencing the emotions of staff and patients.

This study has shown that learning in the clinical environment is complex and there is an urgent requirement for professional education to keep pace with technological advances in CT scanning. There should be an acknowledgment that good teaching and training in the clinical environment is an essential investment in the future workforce. Advanced radiographers should be offered continuous bespoke CT training, with a multi-disciplinary team approach, to keep abreast of current advancements. These radiographers should be given the time, and expertise in clinical supervision and education to set out effective training programmes for pre- and post-registration radiographers in the clinical environment.

11.6 Recommendations

Radiographers are a pivotal part of the modern diagnostic workforce. The profession of radiography should be promoted so governmental bodies, other healthcare professionals, and the public are aware of radiographers' vital role. The Society of Radiographers should promote the fact that radiographers are a specific group within the healthcare workforce, and their prime remit has always been to optimise radiation dose to patients. The Society of Radiographers should advance training pre- and post-registration to fulfill this remit.

Patients should receive the optimal level of radiation to achieve a clinically diagnostic image. Radiographers are required to adjust exposure parameters and scanning technique to achieve this. Advanced radiographers should be offered continuous bespoke CT training, with a multi-disciplinary team approach, to keep abreast of current advancements. Manufacturers should be encouraged to provide regular updates to the users of scanners. These radiographers should be given the time and expertise in clinical supervision and education to set out effective training programmes for pre- and post-registration radiographers in the clinical environment. This occurs with the medical profession supported by Health Education England (HEE) and is being extended to include other professions. HEE must actively support clinical supervision and teaching programmes for radiographers, so radiographers are given equal access to these programmes. HEE must provide money to backfill staff who need to attend these programmes. The Society of Radiographers must lobby the HEE to provide these programmes. Today's radiographers are tomorrow's teachers.

There could be a postgraduate certificate in CT scanning which is required for radiographers working in CT scanning. This would be similar to the Society of

Radiographers accredited certificate of competence in administering intravenous injections. The Society of Radiographers would need to sponsor and facilitate this.

There should be a review of undergraduate courses to make sure newly qualified radiographers are competent in cross-sectional imaging. With the requirement for a vastly increased cross-sectional imaging workforce, direct entry undergraduate CT and MRI courses could be offered. The undergraduate course could be extended to four years, but pre-registration radiographers required to undertake projectional and cross-sectional imaging may be unable to keep up their competencies during the four-year timeframe, and this could cause issues with the limited supply of clinical placements for students. There could also be an extra financial burden for student radiographers if the course is extended by one year.

The HCPC has ignored published evidence such as Sloane and Miller (2017). Instead of actively collaborating with the radiography profession to find out the challenges of newly qualified radiographers undertaking non-contrast CT head scans, it has increased the expected CT examinations a radiographer can perform autonomously upon qualification. The HCPC standards of proficiency for radiographers at the point of registration, from September 2023 will include a broad range of CT examinations and CT Head examinations as part of standards for newly qualified radiographers (HCPC, 2022). The HCPC have not understood that inexperienced newly qualified radiographers could be dangerous operating CT scanners they are not familiar with. The HCPC should consult with the CQC and examine the evidence of the disproportionately large numbers of high dose notifications from CT scans. The HCPC seems to be unaware that newly qualified radiographers do not get to work in CT for some time, maybe more than two years, because they need to concentrate on their projectional radiography when they qualify. The Society of Radiographers has a responsibility to educate the HCPC and to protect its members from being expected to fulfill autonomous roles in sub-modalities such as CT scanning without the necessary clinical training. The HCPC seem to be out-of-touch with the profession.

11.7 Future studies

The longitudinal study followed students from pre- to post registration, it would be interesting to add a third time point into the longitudinal study to assess the radiographers now. By this time some of them may have moved to senior positions within their departments.

Health Education England and/or the Society of Radiographers should commission a wider study to explore education, experience, and social factors effect on CT dose optimisation, which could lead to a consensus of opinion on how to teach CT both pre- and post-registration. There should also be a consideration of how Advanced CT practitioners can keep up-to-date with their training.

The Health and Care Professions Council should commission a study to explore how the recent changes to CT competence at qualification in the standards of proficiency for Radiographers 2022 can be achieved. This further study should include opinions from Higher Education establishments and their affiliated clinical departments.

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Appendices

Appendix 1 – CT parameters questionnaire

Questionnaire (UK)

1) Routine CT scanning parameters (kVp, mAs, slice thickness, pitch, and reconstruction algorithms) should be changed according to which of the following

	True	False
Patient size		
Anatomical region		
Study indication		
Patient age		

2) Regarding Automated Tube Current Modulation (ATCM)

	True	False
ATCM has been shown to decrease patient dose on average		
ATCM can increase the patient dose in the pelvic region		
ATCM should not be used in the presence of metallic implants		
ATCM is affected by centering of the patient within the gantry		

3) Regarding the noise setting (Noise index: GE /Standard deviation: Toshiba /Effective mAs: Siemens + Phillips)

	True	False
The non-contrast phase of an abdomen scan requires the same noise setting (i.e. mAs setting) as the contrast phase		
Readers/reporters can tolerate less noise with obese patients		
Readers/reporters can tolerate more noise with paediatrics		
The noise index should be changed when changes in the patient size are extreme		

4) Increasing the peak beam energy (kVp) from 120-140 kVp causes an increase in CTDI values of?

17%☐ 38%☐ 65%☐ 89% ☐

5) Reducing the kVp from 120-100 kVp for angiographic CT procedures (all other parameters being kept constant)

	True	False
Reduces the radiation dose		
Reduces image contrast		
Increases the image noise		
Increases the vessel enhancement		

6) Regarding the tube current (mA)

	True	False
Tube current has a linear relationship with radiation dose		
Reducing the tube current by 50% increases the noise two fold		

7) Regarding the 'Pitch' (table movement per rotation/ total nominal beam width)

	True	False
Pitch may impact on image quality and patient dose		
Higher table speeds result in an increase in slice sensitivity profile and thus effective slice thickness, reducing the z-axis resolution		
Spiral artefacts are reduced at lower pitch settings		
For single slice helical CT, the higher the pitch, the lower the dose		

8) Decreasing the gantry rotation time (seconds)

	True	False
Decreases the patient dose in a linear fashion		
Increases the image noise		

9) Regarding Slice thickness (selected beam width/collimation)

	True	False
Increasing the slice thickness increases the spatial resolution		
Increasing the slice thickness decreases the dose		
Decreasing the slice thickness reduces "partial volume" artifacts		
Decreasing the slice thickness will increase the scan time		

10) Regarding Reconstruction parameters, choosing

	True	False
A smoothing reconstruction kernel, increases the visualisation of noise		
Wider window settings, reduce the image contrast but also the visual perception of noise		

11) Image noise is influenced by which of the following factors

	True	False
kVp		
mA		
Window width		
Collimation		
Slice thickness		
Helical pitch		
Exposure time		
Window level		
Reconstruction algorithm		

Appendix 2 – Emotional Intelligence questionnaire

TEIQue-SF

Instructions: Please answer each statement below by putting a circle around the number that best reflects your degree of agreement or disagreement with that statement. Do not think too long about the exact meaning of the statements. Work quickly and try to answer as accurately as possible. There are no right or wrong answers. There are seven possible responses to each statement ranging from 'Completely Disagree' (number 1) to 'Completely Agree' (number 7).

1.........2..........3..........4..........5..........6..........7

Completely Disagree — **Completely Agree**

1. Expressing my emotions with words is not a problem for me.	1	2	3	4	5	6	7
2. I often find it difficult to see things from another person's viewpoint.	1	2	3	4	5	6	7
3. On the whole, I'm a highly motivated person.	1	2	3	4	5	6	7
4. I usually find it difficult to regulate my emotions.	1	2	3	4	5	6	7
5. I generally don't find life enjoyable.	1	2	3	4	5	6	7
6. I can deal effectively with people.	1	2	3	4	5	6	7
7. I tend to change my mind frequently.	1	2	3	4	5	6	7
8. Many times, I can't figure out what emotion I'm feeling.	1	2	3	4	5	6	7
9. I feel that I have a number of good qualities.	1	2	3	4	5	6	7
10. I often find it difficult to stand up for my rights.	1	2	3	4	5	6	7
11. I'm usually able to influence the way other people feel.	1	2	3	4	5	6	7
12. On the whole, I have a gloomy perspective on most things.	1	2	3	4	5	6	7
13. Those close to me often complain that I don't treat them right.	1	2	3	4	5	6	7
14. I often find it difficult to adjust my life according to the circumstances.	1	2	3	4	5	6	7
15. On the whole, I'm able to deal with stress.	1	2	3	4	5	6	7
16. I often find it difficult to show my affection to those close to me.	1	2	3	4	5	6	7
17. I'm normally able to "get into someone's shoes" and experience their emotions.	1	2	3	4	5	6	7
18. I normally find it difficult to keep myself motivated.	1	2	3	4	5	6	7
19. I'm usually able to find ways to control my emotions when I want to.	1	2	3	4	5	6	7
20. On the whole, I'm pleased with my life.	1	2	3	4	5	6	7
21. I would describe myself as a good negotiator.	1	2	3	4	5	6	7
22. I tend to get involved in things I later wish I could get out of.	1	2	3	4	5	6	7
23. I often pause and think about my feelings.	1	2	3	4	5	6	7
24. I believe I'm full of personal strengths.	1	2	3	4	5	6	7
25. I tend to "back down" even if I know I'm right.	1	2	3	4	5	6	7
26. I don't seem to have any power at all over other people's feelings.	1	2	3	4	5	6	7
27. I generally believe that things will work out fine in my life.	1	2	3	4	5	6	7
28. I find it difficult to bond well even with those close to me.	1	2	3	4	5	6	7
29. Generally, I'm able to adapt to new environments.	1	2	3	4	5	6	7
30. Others admire me for being relaxed.	1	2	3	4	5	6	7

1

Appendix 3 –Longitudinal study first interviews - Coding table – Education

Code	Phrase	ID
On the job training	I would like some monitoring of first weeks to make sure I am doing right.	UG3
	Learn local protocols and what radiologists prefer.	UG14
	booklets for competency at site, competency sign off, best why diff for every patient, size of pt, area of interest complex. Best learnt on job. Learn local protocols.	UG11
	I would want on the job training. When I have been doing CTPAs I have been learning everything in placement	UG2
	Sitting with radiologists reporting- on the job.	UG4
	one to one tutorial with qualified staff.	UG1
	on the job, as a newly qualified then mainly in house	UG9
	Freely ask questions to the senior members and get an answer, freedom to ask silly questions if I need.	UG8
	On the job day to day training	UG8
	Enough training on how to use equipment and enough time to get my head around the protocols - On the job training.	UG10
	They have more than 1 type of scanner so it would be good to learn on all scanners so I know how to scan on all of them.	UG10
	on the job, practical training,	UG6
	On the job training, following senior people, get advice watching what they do, I find myself doing things but not understanding why.	UG7
	because CT is so fast paced i need to get more familiar with my surroundings because I have been there as a student.	UG7
	I know at my site it has booklets which they ago through all the competencies, all the training required to ensure that everybody is completely confident and competent in CT before they start working properly in CT and at the required level to be able to do that.	UG14
	When you actually do they job you realise that it is different for every patient and that every patient is a different size etc so it can be quite complex so best to be learnt when you are actually on the job.	UG14
	Sitting with radiologist and learning.	UG2
	……but you either do it by a course or through competency training while you are in work, which I think is the best way to do it because at the uni we don't wont to be spending too much time on CT when most of us will just be going into general Xray jobs to start with then doing CT training when CT is changing a lot as technology and protocols develop .	UG14
	Comp sign off so they can identify things that you may not know , they would teach you on the job,.	UG14
	In future, I dont think for practical aspects they can be anything to gain over what you can learn on job and doing your own research, keep current in your work.	UG14

Code	Phrase	Number
Postgraduate training	I would like to come back to uni to feel confident, but I know it can be a problem with funding.	UG7
	Formal post grad CT, to be able to do cardiacs.	UG4
	Reporting in CT as radiographer- Post grad.	UG4
	if I was to advance in CT then it would be out house post graduate knowing to adapt the exposure factors , knowing how things effect each other and stuff like that.	UG9
	Study Post Grad and extra research, depends on department money and whether they think it is worthwhile.	UG10
	possible positioning at Uni, post grad CT course.	UG6
	CT reporting being expanded would be good as a radiographer's expanded role because I have heard and seen a little bit about that in papers and taking to people by how that might be something that radiographers might start to take on.	UG14

Code	Phrase	Number
Undergraduate	At uni already but get to know how the machine works from a practical point of view.	UG13
	I think we've probably already have the physics knowledge under our belt	UG12
	With a C T scanner in uni, workshop if no uni scanner available.	UG6
	Basic positioning for undergrads.	UG6
	Adequate training in CT at Uni we haven't gone into overload of detail	UG14
	Training that you are not doing straight away would probably be out of date by the time you get to do it in a year 18 months time if it takes that long so you would want to do that while you start working.	UG14
	Formal training will not be necessary.	UG14

Code	Phrase	Number
Study days	I love learning so I feel the practical side not enough. Thought on study day when patients are not around, could be onsite.	UG7
	Study days talking to other people who use similar scanners would also be useful for learning the best ways to use the scanner efficiently and as dose optimisation methods because at the end of the day if you get stuck doing one thing one way and you think it is the only way to do this thing and then somebody was to turn round and say oh no you could do it like this then it is ultimately better you would want to know that sooner rather than carrying on doing your own thing for however long and then just find out that there is a better way to do that.	UG14

Code	Phrase	Number
Applications training	Applications training to help change parameters for different types of patients.	UG13
	definitely the technological and hardware and software applications, just training programs for particular machines	UG12
	Apps training, different settings or parameters of CT scan.	UG5
	Applications because they don't show how to use, just click on this and click on that not really explaining it.	UG5
	User group meetings with be useful, find out about new systems.	UG11
	If learning on job person teaching may not know how to reduce dose or efficient use of scanner so apps specialist better.	UG11
	Application specialist, I think it would be a good idea.	UG9
	Apps training days useful different ways of doing things to give more options you would need that because while you can learn everything on the job if the person you are learning from doesn't know how to do a certain thing you might be able to optimise dose by doing it a different way or their might be a way to improve the efficiency of the use of the scanner and be able to get more patients in over an amount of time while still producing better high quality images.	UG14

Appendix 4 –Longitudinal study first interviews - Coding table - Dose optimisation

Code	Phrase	Number
FOV	Probably areas you don't need to see. You need to see liver and associated vessels. You could adjust the FOV, cut it down little especially on pre. We go down to crest and include bladder.	UG7
	Small adult, use smallest FOV, reduce kV to lower amount to keep dose as low as possible,	UG6
	Triple phase liver, on repeat miss out scanning whole abdomen	UG12
	Optimise procedures, If just liver just scan liver to reduce dose to patient.	UG11
	Don't scan unnecessary areas,	UG11
	It would be good to reduce if you can specify exact area you want to look , you could reduce dose at so if you just wanted to scan one part of the abdomen you could do this instead of the whole of the abdomen. if you were just checking on a tumour you could just scan that area but if it was a cancer and it did come back but you only scanned one reduced area, by not doing the whole abdomen you may miss something there.	UG8
	At this stage would use the same FOV as the original one.	UG4
	Try and identify where liver starts and ends on pre-scan and make sure you get correct FOV on other scans.	UG6
	You have got to be optimising the procedures and the protocols you will be using for patients having repeat scans ensuring that you do not scan unnecessary areas. We do a 3 phase liver but on the repeat one you might want to miss out scanning the whole abdomen, I would check with the doctor if there was any new information, if they say it would be absolutely the same then it was just the liver they were looking at then we would only need to scan the liver to try to reduce dose to the patient.	UG14
	I do feel during the scans you can look through the other ones to make sure, because you said that there is a delay, to make sure that you haven't missed anything or make sure you have the optimal views you are looking for, the patient is positioned correctly and other things.	UG9
	Non- contrast of liver then 2 other scans, flexibility within sequencing to change things and whether you want to repeat the whole thing every time.	UG9
	Discuss with doctor if more information required from rest of abdomen.	UG11
	FOV-I guess that would depend on the radiographers, you know, for the knowledge as it were of pathology, of anatomy, really sort of this is more radiologist territory, I think, but it would be good if radiographers learnt more about it definitely, because it's still highly relevant and we are the ones doing the scanning.	UG12
	I don't think that the expected norm of radiographers	UG12

Code	Phrase	Number
Reduce exposure	We have different settings on our machine, so for smaller patient you choose the anorexic patient protocol. For a larger patient you choose the obese protocol. For a medium patient you choose a medium because it gives you different exposure factors so there is different dose for a patient. Smaller patients would not need as much as a larger patient, that needs to be taken into consideration.	UG9
	As low dose as possible, lifetime dose will be high. To minimise that use dose optimisation.	UG10
	On smaller patient can reduce penetration more radiation reaches detector.	UG11
	Very large patient or other extreme very small. You have to be very careful what dose you are giving them.	UG3
	Image noise increases when not enough radiation has been used to produce the image and it does therefore reduce the resolution and the diagnostic information which can be achieved using the scan so dose optimisation should be about not just using the lowest possible dose but using the lowest that will give the best diagnostic quality image without too much noise.	UG14
	More noise and less dose? causes problem if you miss something if image quality not at a diagnostic std	UG3
	Larger patient more exposure, mAs and kVp. If small would bring exposure factors down as much as I can. Drop kVp and mAs	UG10
	Try to make sure you have enough dose to penetrate through tissue and try to reduce noise and scatter on images.	UG6
	Well, I mean the relationship is given the power of reconstruction, the more dose you give, generally, unless you really over expose, the better image you're going to get. You could say that, if you're happy to accept slightly inferior images you can optimise dose, because you can give a patient less dose, but you know if you want a decent image, it is necessary to ensure you have more dose than necessary than less dose than necessary, if you see what I mean. Yes, it is linked, I would say, but only if you're willing to compromise	UG12
	Dose optimisation you need to compromise and image noise as well. So if you compromise that then you compromise image noise a little bit as well. So I do think that there is a relationship.	UG9
	If you have a slim pt take the kVp down. If you have dose modulation you can take it down, you can adjust mA and it will do it automatically. If 5 year old-go onto kV and reduce to 60kV. Want to decrease dose, a lot of radiation to paediatrics, especially scattered radiation. Want to protect them.	UG2
	I would reduce the amount of mAs used and try to keep the kV to 100 kV. Reduce mAs because that is amount of X-rays being produced so keep as low as possible.	UG6
	Noise increases when not enough radiation being used. Not just using lowest possible dose, lowest dose giving diagnostic image using minimum dose.	UG11

Code	Phrase	Number
	For smaller patients it should be reduced because you don't need to use as much radiation on a smaller patient because a lot of the radiation will pass through to the detector so you can reduce the penetration and the mAs and again you have got to check that the automatic system is doing it correctly before each exposure.	UG14
	Less mA or you use or higher kV can be used in dose optimisation to reduce mA will reduce dose to pt but you may get a much more grainy picture. This is increased image noise you can have up to a certain extent but you need to have a diagnostic image.	UG8
	bigger body size increase exposure factors.	UG1
	Take chest down to 100 kV for slim patient. If larger patient leave on 120 kV. If want to enhance contrast give low dose scan, like CTPA.	UG2
	If using contrast can take dose down, vessels are area of interest. You can take dose down.	UG2
	Noise can increase if dose is not enough to penetrate through patient's skin. It will not be clear.	UG2
	When you get really big patient while the scanner has smart mA systems to optimise the dose for different sizes of patients and different parts on the body , some patients have really large abdomens but then go down to skinnier chests so obviously it want to be adjusting and adjusting as it goes round, it have 4 quadrants I think so it gives different dose when going through from the front rather than going though from the side and to give optimal dose and optimal image quality. But larger patients would require more dose otherwise it wouldn't be able to give better image quality and there would be less resolution.	UG14
	You're more likely to be using a higher kV to punch through all of the patients extra, you know, tissue and fat, so in that respect I mean yes, I mean the dose will be bigger but I mean it is necessary and yeah it's as simple as that. I wouldn't turn off the AEC and try to go with my own mAs plotting. I would still use the AEC, but I would again, sort of, refer to the user interface, look at the little graph and make sure that I have got an appropriate modulating, I mean yes, I suppose I would accept a less wiggly line because if the patient - if there is a lot of fat, sort of uniform density of the patient will be more similar than with like a skinny patient then you will have more extreme differences obviously, like between the lungs and the abdomen, so I would find that more acceptable to have a less sort of modulating current, but I would still aim for modulation I wouldn't not adjust the kV.	UG12
	If pt bariatric and adult would increase the dose to be able to image the patient. otherwise would not be able to see the structure properly *small adult? Yes definitely,*	UG13
	So what I see radiographers choosing different {programmed} parameters not changing manually.	UG5

Code	Phrase	Number
justify exposure	For FU on lymphoma patient? *When CT used with PET/CT in yes lesser dose, if CT being used individually then insight need to use higher exposure factors to get more detailed information unless you can monitoring it using other imaging that doesn't use radiation.*	UG4
	When you do a liver and they are different protocols this will have an impact on pt dose, judge risk and benefit. i am not sure of the benefit at the moment. I don't know extra chance of cancer from doing an extra phase, it could be the same as flying to Australia. depends on age, if pt old already it's might be justified to do an extra scan. Younger pt has a much longer time in life to develop that cancer	UG8
	Say they were repeating it about a week later you would have to discuss with the doctor its there would be any new information that they require the rest of the abdomen.	UG14
Collaborative working	MPE, Radiologist plus radiographer working together to change protocols	UG13
	for biopsy	UG5
	….. for new scanner not on a daily basis	UG2
	For new protocols and applications, they all work together	UG14
	To change protocols and for approval	UG1
	Only seen superintendent and radiologist working together	UG4
	When new protocol trialled, MPE and radiologist and application specialist when new protocol written. Needs to be approved by MPE and Radiologist	UG11
	I have seen it (collaborative working) during a biopsy, the radiologist let the radiographers know how they want things	UG9
	For new scanner, for cardiacs	UG6

Code	Phrase	Number
Exposure parameters not adjusted	Just guess, reduce mA and maybe reduce kV a little bit, less vol going through. Never seen a child scanned.	UG8
	Not sure in this hospital can choose parameters for children and different body sizes.	UG5
	Not seen in practice.	UG13
	Change kV and mAs changes by itself. you put in dose you want to start on it then regulates itself, I don't knowhow it works.	UG4
	I am no quite sure, use paediatric setting maybe reduce a little bit is necessary.	UG6
	I haven't seen then change dose for a child or adult	UG13
	It seems to be radiologists that have more training and more knowledge and it is generally them I've encountered who make these calls, but I'm in favour ...	UG12

Appendix 5 –Longitudinal study first interviews - Coding table - Culture

Code	Phrase	Number
Asking questions	I should have asked questions when I didn't understand anything. A lot to learn that we haven't been taught. there is a lot that we will, have to learn.	UG8
	Freely ask questions to the senior members and get an answer, freedom to ask silly questions if I need.	UG8
	Discuss with doctor if more information required	UG11
Team Working	…….also communication with staff as well working in a team where I have had lots of experience with.	UG9
	there's not a lot of licence for deeper thinking it's very much a case of, "Oh ok we are doing a three phase liver, because the request ticks these boxes and it's signed by the radiologist".	UG12
	Communication with staff as well working in a team where I have had lots of experience	UG9
	No core CT team	UG7
Explanation of protocols	I was going to say, let radiographers set the protocols themselves after all of this training because after all we are the ones doing the scanning	UG12
	You can do different protocols for different radiologists.	UG4
	Would like to have had protocols explanation of why they change They recently change to include liver in chest CT nobody explained why.	UG4
	Just go off local protocol.	UG7
	Have added on protocols, you just click on it and it will come up	UG2
Passive role	As a student, where I work in CT it is very fast. Major trauma students just helping patients getting on and off table.	UG3
	Sometimes we get to press the buttons but not very often so we don't get involved in those aspects.	UG3
	You need to understand why you are doing it.	UG7
	Following senior people, get advice watching what they do, because CT is so fast paced i need to get more familiar with my surroundings.	UG7
	I think CT radiography is very much a case of following the protocol that is set by the radiologist.	UG12

Appendix 6 –Longitudinal study second interviews - Coding table - Education

Code	Phrase	Number
Undergraduate	So, you think it would have been useful to do like some phantoms? If they had it, yeah beforehand.	PG6
	I think to be I think to be honest it's probably largely stayed the same. Honestly, I don't remember what I thought of these things. I feel it's probably more knowledge-based than back when I was a student in terms of practical knowledge rather than just book knowledge just be the work I don't know.	PG14
	I would love more training in to understanding this kind of properly and all the protocols and changing things, and yeah I have no time to focus on anatomy and all the stuff I love	PG7
Postgraduate	And would it be useful to do a postgraduate qualification in CT Yeah like if you were doing a manager's job or in charge then yeah it would.	PG6
	I have no time to concentrate on anatomy, pathologies and the more technical aspects of scanning, like all of these dose reductions and all the technical terms and understanding what you're doing on the scanner properly. A message comes up if the scan times too long to increase the kV and decrease the dose right index, but I don't know why I'm doing that	PG7
	Yeah so, I'm now training in cardiac scans and it's really interesting and this morning I was just helping my colleague with the enema, I'm hoping in the future I can get more involved. I would like to attend courses for advance technique.	PG5
	The more technical things, I'm not sure there is time in the day, I think I'd have to go to a course in uni or in my own time, yeah. Or just read up on it, maybe. But that's the thing, because it's not the speciality I want to go into.	PG7
	Postgraduate course on tumour imaging definitely	PG4
In-House	I don't think there is much once you work in CT you understand about it anyway. So, you're picking up all those aspects from working there? So, on the job training?	PG6
	X was doing it before I was born. They are very experienced very knowledgeable and happy to share all that knowledge and teach.	PG14
	They are great teachers that know a lot like a fountain of knowledge and they are very happy to share it, so you learn an awful lot even with the odd day just here and there. It's been really good.	PG14

Code	Phrase	Number
	I think I do learn everything we need and when we're expected to do it all on our own, without everything that we need to know, it would be interesting but more for our own interests. Like I don't think here it would change what we have here because we are involved in everything that is going on with not just sort of told to watch. From the first day we're involved in everything, so we pick it up as we go along. We're encouraged to ask all sorts of questions on anything that we see that we don't understand that's going on and we are encouraged identify that and do our own manual work.	PG14
	so I sort of had quite a lot of knowledge and worked in CT before, however I know now since I have started - since we've have got new people they have got a competency checklist but I must have sort of missed them introducing that and being hot on it. So I have never signed the competency checklist. However, for my band 6 there's lots of things you need to tick off and that's one of them so I am going to have to go back and tick everything off and I am starting difference of procedures in CT now. So no actually I never signed that before I started anything.	PG7
	I think it would be really nice to sit with a radiologist maybe when they're reporting the CTs because you get so much from that, the things that you don't notice. They spiel off and it draws your attention to things, because it's the same with plain CTs, like I love sitting with the reporting radiographer. I think that would be good for that bit. The more technical things, I'm not sure there is time in the day, I think I'd have to go to a course in uni or in my own time, yeah. Or just read up on it, maybe. But that's the thing, because it's not the speciality I want to go into.	PG7
	We have structured training, going to CT in afternoon. It is a new type of training here. We take on the ARA role and spend the afternoon in CT, which frees up ARAs to go elsewhere such as A/E or MRI which they enjoy. I just have just started this training, 3 of us (most qualified band 5s) have started this new training. It is working well, not too rushed. If we have staffing problems, somebody could be taken out of CT for the afternoon.	PG10
	We have sessions with physicists as part of our training.	PG10
	We had like those CT dose tutorials with the medical physicist there but not the radiologist	PG5
	Lots of CPD sessions. Do them almost every week now. I wouldn't say at lunchtime , they do organise them every week but not everybody can go to every one. Somebody has to stay behind .	PG4
	It's an advantage that the people who actually know these things can do the teaching sessions.	PG4
	In previous job………Somebody did a dose reduction course but they only focused on X-rays, not CT, but based on that yes it would. It did make a difference knowing what you could do.	PG4

Code	Phrase	Number
Apps training	I might find a Toshiba users' day useful	PG6
	I have no time to concentrate on anatomy, pathologies and the more technical aspects of scanning, like all of these dose reductions and all the technical terms and understanding what you're doing on the scanner properly. A message comes up if the scan times too long to increase the kV and decrease the dose right index, but I don't know why I'm doing that	PG7
	............if they came in to show us how to programme the scanner or if they did the software or something that would be useful as well.	PG5
	Never been directly taught by application specialists always taught by people who have been taught by them.	PG4

Appendix 7 –Longitudinal study second interviews - Coding table - Dose optimisation

Code	Phrase	Number
Exposure parameters	depending on the patient's size, patients age, what are you a scanning, what you are scanning for and what results you might need out of it and that the use of contrast might affect your scanning parameters.	PG14
	So, the exposure parameters would not need to be as high. Often the machine would calculate it automatically, we would expect the exposure factors and the dose given at the end of it to be a lot lower. Both for the radiation protection of the child and because not as much exposure would be needed to produce diagnostic results.	PG14
	an increase in body size might mean you might need an increase in maximum mA allowed and may also consider increasing the kV to allow penetration through the larger mass.	PG14
	mainly, if its paediatric you're in that mind set of changing and picking different things, but day to day, unless there is an obvious, bigger or smaller, I don't (change parameters).	PG7
	The protocols are set up, we have sort of got an indication of patient size, if it's 32 and over we go up to the large protocol and then we've got like an average protocol.	PG7
	unless they are very out of the average spectrum or a paediatric, I don't think I would be confident enough to change it.	PG7
	for chest, abdomen, pelvis, and for any other scans, we don't have any paediatric things set up at all	PG7
	for head scans, so we have got, sort of set up, I can't remember the exact sort of thing, but we have got like 1 to 5, 5 to 10, 10 till 15, I think, and then just the adult	PG7
	I might have in my head, "Like oh I'll go down to the lowest", which I think is 80. I think it's mainly set up at 120 so we can go down to 100 or 80. But then it depends how big they are; you need to judge it when they come round.	PG7
	MPE has set paediatric settings on weight of child in kgs. CT scanner has settings for 0-1, 2-3 etc and then weight within settings, plus chart of average weight. May have to select 3 year old setting for older child depending on weight.	PG10
	on one of the scanners we have a HD scanner and there is like a protocol called kV assist so when we have the smaller patient and we use the kV assist we can tend to bring the dose down so it's much lower than non-kV assist protocol.	PG5

Code	Phrase	Number
	I used to think that on children for example head scan it's always grey like grey images, but our superintendent told us that because in paediatrics the skull is so thick, like so dense so and then we got the right protocol is being set up, based upon the XX tumour hospital protocol. So, yeah, it's normal, it's fine to have those kinds of images.	PG5
	Because for our arterial for liver we just do the abdominal area so below the diaphragm to the iliac crest and then we do the Porto venous phase abdo-pelvis.	PG5
	I think the field of view you're trying to get is the same field of view you got before and then the collimation bit, I mean the box always keep it minimum anyway so.	PG5
	He did teach us how to do it for young patients you had a protocol that was already programmed in, but for elderly people for that one you would change the kV accordingly. (Adult program) just change the kV.	PG4
	You would use 80 for a little elderly person you wouldn't give that to a baby that was too big too high for them so adjust even further. 5 year old child …….change the paediatric one.	PG4
	(Larger patient) You can only go so high because most of the X-rays are going to be absorbed in the set tissue anyway. I would diffinatley need somebody with more experience to help me.	PG4
	(Adjust exposure) it would normally do it automatically	PG6
	Incorrect positioning for scout view)I don't think it matters here. It automatically adjusts to work out.	PG6
	Normally we'd keep it the same. So, it would be the same throughout. You would slightly change the exposure, so it is lower if they are using contrast.	PG6
	So, if it sets the child exposure, you would keep that, but you would make sure that the dose is as low as reasonably possible for it. So, it would be closer to 80 kV or 100 depending on what the lowest settings are. (Paediatric protocol) I haven't seen it but I'm guessing there must be	PG6
	there is a need depending on the patient's size, patients age, what are you a scanning, what you are scanning for and what results you might need out of it and that the use of contrast might affect your scanning parameters.	PG13
	Large or strange shape of very small? I thin it is good practice to do so.	PG13

Code	Phrase	Number
	the exposure parameters would not need to be as high. Often the machine would calculate it automatically, we would expect the exposure factors and the dose given at the end of it to be a lot lower. Both for the radiation protection of the child and because not as much exposure would be needed to produce diagnostic results.	PG13
	Dose optimisation should be about using the optimum dose to give good diagnostic value of images, it shouldn't be just about reducing the dose. Dose optimisation should be without getting a noisy image, a low dose, obviously if you reduce the dose the noise may increase but you do not want to reduce the dose so much that you get too much noise for diagnostic value.	PG13
	obviously so basically considering previous imaging and what imaging is going to be done in the future,	PG13
	if a patient comes, particularly for oncology or something like that, all the previous imaging, all the previous relevant imaging should be imported to ensure that we are not. If they had a I don't know, if they had a CT scan yesterday, and then they were referred to us then we don't need to scan then again just one day later. So, you need to consider all of that.	PG13
ATCM	You would have to consider the maximum tube current allowed. Whether you would need to increase or decrease that, you'd have to consider the patient size and the area being scanned.	PG14
	The centering of the patient, we have got to make sure that they're in the isocentre; not too high, not too low.	PG7
	Carefully position for topogram.	PG10
	I think bring the arms up whenever possible when possible just to reduce dose to that area	PG5
	With the positioning at a certain point.	PG5
	Could make manual adjustments but this is not encouraged.	PG10
	Yes, an increase in body size might mean you might need an increase in maximum mA allowed and may also consider increasing the kV to allow penetration through the larger mass.	PG13
Metallic implants	There is CMAR reconstruction that you can do with metal implants	PG6
	Oh this person has got a double hip replacement, they're going to have a beam hardening artefact, therefore we should maybe turn off AEC	PG12
	Metallic implants and stuff, we have a separate scanner that we normally do, people with any sort of metal	PG7

Code	Phrase	Number
	One of our scanners has OMR, which is metal reduction software. We will normally scan them on a separate scanner to reduce that.	PG7
	There is a metallic hip setting to reduce scatter from hip, images still have lines but really helps with orthopaedic patients.	PG10
	We have the iMARS – the implant metal artefact reduction.	PG5
Collaborative working	We had like those CT dose tutorials with the medical physicist there but not the radiologist	PG5
	We have sessions with physicists as part of our training.	PG10
	we don't have any on-site medical physics experts, we have medical equipment on the site, but we use an external site for a medical physics now I don't know why	PG14
	Never seen a CT MPE, but they were at a different hospital and only came for courses. Because we weren't CT radiographers when they did the CT it was to the CT group.	PG4
	MPE has set paediatric settings on weight of child in kgs.	PG10
	I think they are internal, because I asked about QA and they say that they should talk to the medical physics.	PG13
	Radiologist- so at the moment, they are just trusting everyone with that and when they are first in they always come in to say this is what they want.	PG6
	Radiologist decides on protocol including recon.	PG10
	We had a chest specialist who said give me a low res image not a high res where as others always asked for a high res. but for him he was more than happy to report on that. It just depended on which radiologist you spoke to. They would specify which protocol they would want.	PG4
	So I've seen the radiologists and the radiographers work together for biopsies and interventional procedures etc	PG14

Appendix 8 –Longitudinal study second interviews - Coding table - Culture

Code		Phrase	Number
		I'd say I was confident with at first, but know we do the CTPA's, anglos; we end up doing all sorts on night shifts	PG7
		it has boosted my anatomy and what I have learnt from uni makes more sense now, the physics part makes more sense	PG13
		t's probably because I stayed in the same place, I think I've always known what to expect when I came here	PG14
		so I sort of had quite a lot of knowledge and worked in CT before	PG7
		I was so much afraid to confront it, but I'm not saying it's easy, easy, but I have a positive opinion now rather than when I was in uni. Maybe because of where we were trained.	PG13
		if you think back to how they treated you when you first began then at least you would turnaround .... and say you know what just show me what to do	PG4
ACTIVE ROLE		Crazy, nonstop.	PG7
		last Saturday I did an extra list, a CT2 list, where we do, sort of, mainly chest mandible non-contrast stuff. A whole list of people, 9-5, every 10 minutes, just to catch up and we do those most weekends and then we are fully booked in the week,	PG7
		20 CT scans in a night shift	PG6
		you wouldn't have time to be running to get somebody else.	PG14
		I think because I already had some experience here and I pretty much went straight into CT, I was ready – I wanted to do it because it's so busy	PG7
		I feel like I got more experience than other people have from other places because it's so busy.	PG10
		So, you were getting a fantastic amount of experience here in a very short time.	PG10
		They did allow us to do bank shifts over the weekends. So if you wanted the experience you would just give up your extra time.	PG4
		So you get your workload, it's a lot faster and you get more range of patients coming in	PG6

Code		Phrase	Number
		From the first day we're involved in everything	PG10
		if I'm not mistaken but the CT team and the medical physicists are there.	PG5
		if they were in the same place we could help each other with manual handling and I think it would just run better.	PG7
		I have scanned out of hours under the supervision of colleagues to keep my hand in.	PG10
TEAM WORKING		because you want to feel part of the team and when you're not cannulating, you can't be a fully competent member of the team.	PG7
		We have structured training, going to CT in afternoon. It is a new type of training here. We take on the ARA role and spend the afternoon in CT, which frees up ARAs to go elsewhere such as A/E or MRI which they enjoy.	PG10
		But night shift is particularly hard, because there is only two of us. Since I started doing night shift, depending on who I am working with.	PG14
		You have all the interdependencies that you would need to work in a busy heavy workload environment and we do hold a very high standard here as well and like I said all of the experienced radiographers are happy to share their knowledge and support us all through it, because we're all in the same boat.	PG10
		We're encouraged to ask all sorts of questions on anything that we see	PG10
		I would often see a lot of CT there. Because you would have to go and give them a hand, sizing the patient and all of that, so they would do some teaching whilst we were doing that, which was quite good.	PG14

Code		Phrase	Number
		we had quite a lot of staff when I started and I got quite a nice induction	PG7
		Every 3 months you would go there for a week as long as you didn't get transferred back to generals	PG4
		We have structured training, going to CT in afternoon.	PG10
		Because you're off doing your own things, whereas when the responsibility is on you and you have the day list and you understand the system more and I can see the request list and see how many patients – I don't know. That's what I feel, I feel like it's crazy. I never thought it was going to be like this.	PG7
		So, you get your workload, it is a lot faster and you get more range of patients coming in then you would normally here.	PG13
		I do think about it, like a triple phase liver, depending because I am not a CT, I would only do what the radiologist wants, because during the night when they bring their request, we have to consult the radiologist.	PG13
		Yeah but oh I'd have to query the stroke. Or any heads I'd query stroke or seizure depending on if they put protocol 1 or protocol 2. We'd do them all day or all night.	PG6
		normally it's part of the induction, it's meant to be, but it was kind of a bit rushed, but I did get some later on.	PG13
Autonomous practitioner		we were pretty much independent. Which I think is a good thing because you get more experience.	PG10
		I've learnt a lot and sometimes you have to make decisions yourself, you have to, it has really helped me	PG13
		So normally we are split up most of the night, 1 person is in CT all, 1 person in A/E all nigh	PG7
		……you have a bit of knowledge behind it and actually make a decision	PG4
		for our night shifts you need to be CT competent with the emergency scans to do the night shifts, so we do, do them as a band 5.	PG7

Nurture		The head of CT is always working in the CT department because they were short staffed so he knows day on day what's going on in there	PG4
		We're encouraged to ask all sorts of questions on anything that we see that we don't understand that's going on	PG10
		…….was doing it before I was born. They are very experienced very knowledgeable and happy to share all that knowledge and teach.	PG14
		they know what you're able to do what you're not able to do and they won't expect you to do things that you can't do.	PG14
		I was supernumerary in there, and we had quite a lot of staff when I started and I got quite a nice induction, where I could just concentrate on learning and go off and do things and shadow people	PG7
		We have sessions with physicists as part of training. Physicists set up protocols on scanner such as ones for children. If we have a problem or we want to review protocol we call the physicists, we have them on site.	PG7

Negativity		so they would complain if it's so grainy, in spite of the scanner being old or - they expect you to adjust the protocol, choose the right protocol to bring an ultimate image.	PG13
		But they refused one …….I thought it was quite serious, but they were annoyed with me for not consulting them	PG13
		No you should have consulted me	PG13
		but instead of sitting down and showing us how it is done some treated you as if you were dumb while other treated you well which was really good and others just refused to work with you.	PG4

Appendix 9 – The semi-structured interview questions

Research aim:

- The research aims to identify any training requirements for UK radiographers in CT and identify whether education and/or emotional intelligence has a bearing on a student radiographer's approach toward dose optimisation in CT

1. Introduction

- Do you have any questions regarding the participant information sheet?
- You have signed a consent form and I would like to remind you that:
    - Agreeing to join the study does not mean that you must complete it, you are free to withdraw at any stage without giving a reason.
- Please can you tell me your age?
- Please can you tell me if you have a previous degree or post graduate qualification and if so please can you.
    - Inform me of the title and its classification.

2. Theoretical scenarios

- Do you think there is a need to adjust exposure parameters in CT scanning?
- Would you consider changing the exposure parameters for a 5-year-old child?
    - Prompts: *Why, which ones, how?*
- Which things would you consider when using an Automatic Tube Current Modulation (ATCM)
    - Prompts: *What would you do if the patient was incorrectly positioned on the topogram (scout view), metallic implants, and different regions of the body?*
- Would you consider the reconstruction parameters when thinking about dose optimisation?
    - Prompt: *Iterative reconstruction*
- Do you consider body size or shape to have a bearing on dose optimisation?
    - Prompts: *Would you reduce mAs for a small person? Would you consider measuring a patient before the scan? Would you consider changing tube current (kVp)?*
- Do you believe that there is a relationship between dose optimisation and image noise?
- Do you think that the sequencing of scanning has a bearing on patient dose?
    - Prompts: *The use of contrast media,*
- What do you consider the value of Diagnostic Reference Level (DRLs) in CT scanning

3. Views on training requirements and learning styles

- Can you suggest any training that you would consider desirable to enable you optimise dose whilst working in CT scanning?

4. Practical experiences

- Have you experienced any collaborative working in CT scanning to setup or change exposure parameters?
    - Prompts: *MPE, Radiologist*
- Have you ever seen radiographers checking/recording the DRLs?

Appendix 10 – Prompt questions for focus group

CT patient dose optimisation

* Do you adjust exposure parameters
* Technical advances influence how you optimise dose?
* Do you look at/record diagnostic reference levels?
* Who decides how to optimise dose?
* Do you adjust for specific patient, children, bariatric patients, low BMI patients?
* Do you optimise dose with phantom work
* Do you think about reconstructions when you adjust dose?
* Do you use the Field of View to optimise dose?
* Do you set or adjust protocols?

Training and education

* What type of previous education have you had?
* What are your views on, on the job training
* What are your views on, In-house teaching sessions
* What are your views on, Study days
* What are your views on, Competency
* What are your views on, Post graduate training
* Do you receive training from clinical scientists

Collaborative working

* Who decides on protocols?
* Do radiologists work with CT team to set protocols?
* Do applications specialists set protocols?
* Is there interaction with clinical scientists?
* Are protocols set due to an historic process?
* Is the setting of protocols an iterative process?

Culture of the clinical environment

* Do you work as team?
* Is there a hierarchy?
* Do some teams work better than others?
* What is the culture like?
* Does the culture influence setting protocols?
* Whose opinion has the greatest weight
* Has Covid-19 had an effect?