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Comparative Analysis of Global Access to Computed Tomography (CT) Services: Radiographers' Experiences in Ireland and Sub-Saharan Africa

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Candidate Declaration

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I declare that the thesis entitled *'Comparative Analysis of Global Access to Computed Tomography (CT) Services: Radiographers' Experiences in Ireland and Sub-Saharan Africa',* submitted for the degree of MSc in Medical Device Technology and Business, is a result of my own work and that, where reference is made to the work of others, due acknowledgment has been given. I also declare that I have not plagiarised the work of anyone else, either partially or entirely, including the work of other students.

Candidate signature: _________________

Date: 18/08/2024

Supervisor name: Dr. Áine Behan

Supervisor signature: _________________

Date:

Acknowledgements

This research is dedicated to those working toward achieving universal healthcare equity without discrimination or disparity.

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Abstract

Background: Nigatu *et al.* (2023) reported only 14% of developing countries have one CT scanner per million inhabitants, compared with 100% of developed countries. This research aims to address access disparities in CT imaging between developed and developing regions, taking Ireland and Sub-Saharan Africa as representative regions. The research examines the user experience of CT radiographers in each region to determine whether demographic and contextual factors may influence the user experience and/or access to CT imaging services. The research subsequently seeks to assess whether region-specific solutions could address access issues and usability challenges in each region, while advocating for inclusivity in medical imaging equipment design.

Methodology: This research employed a positivist framework and an abductive approach to examine the user experience of CT radiographers in Ireland and Sub-Saharan Africa. This was achieved through a semi-structured online questionnaire containing 30/31 questions which covered attitude, behavioural, classification and pre-coding questions. The questionnaire contained primarily closed questions, with some optional open questions to add contextual information, and covered demographic and contextual factors, usability assessments and ranking questions to address critical needs and priorities. The questionnaire was sent to CT radiographers in Ireland and SSA via social media and email distribution, achieving 52 responses in total, 31 from Ireland and 21 from Sub-Saharan Africa.

Results: Several notable commonalities and differences were observed between the examined regions, both in terms of CT system usability and accessibility. However, the increased abundance of CT scanners in Ireland relative to SSA meant their shared challenges were of differing impacts in each region. Radiographers in both regions were generally satisfied with their overall user experience, although they identified both shared and unique areas for improvement when asked. Both cohorts identified issues with CT scanner hardware, particularly the scan table weight limit and gantry bore size. Others identified confusing or problematic user interface features. The most significant differences were in respondents' rankings of critical needs and priorities, specifically CT access barriers, CT-related issues, and CT system features. Radiographers in Ireland were primarily concerned with workforce and training-related issues, as well as achieving diagnostic and technical accuracy. In contrast, radiographers in SSA were focused on financial and infrastructural challenges, also demonstrating a strong commitment to patient-centred care.

Conclusion: This research underscores the need to implement region-specific strategies to enhance CT imaging services in both regions, with a focus on addressing their most critical needs and priorities rather than focusing on usability challenges. This is essential to improve patient care in both regions and ensure that progress is made toward achieving equitable healthcare.

Keywords: *human factors engineering, medical device design, medical imaging, user need, usability, accessibility, biases in medical device design, inclusion and diversity, computed tomography, radiographers*

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Abbreviations

AI	Artificial Intelligence
CPD	Continued Professional Development
CT	Computed Tomography
HFE	Human Factors Engineering
HSE	Health Service Executive
MPR	Multi-Planar Reconstruction
MRI	Magnetic Resonance Imaging
NGO	Non-Governmental Organisation
RSM	Radiography Services Manager
SSA	Sub-Saharan Africa
UI	User Interface
US	Ultrasound
WHO	World Health Organisation

Chapter 1: Introduction

This research explores the current landscape of medical imaging services in developed and developing regions with a focus on computed tomography (CT) in Ireland and Sub-Saharan Africa (SSA). In this research, CT scanner usability and accessibility are examined from the perspective of the radiographer, with an aim to identify any correlation between challenges with usability and accessibility and demographic or regional factors. This research aims to evaluate whether region-specific design features could help to enhance the user experience among CT radiographers and/or make CT imaging more accessible. This research aims to use the findings to provide recommendations to enhance CT imaging services in Ireland and in Sub-Saharan Africa.

1.1. Research Significance

This research aims to uncover any biases in existing CT systems and encourage system manufacturers to design with consideration for demographic and contextual differences, specifically in developed and developing countries. This research believes that listening and responding to the needs of radiographers in varied contexts could also help enhance access to CT imaging services in respective regions and improve the provision of high quality and timely healthcare.

1.2. Research Background

In medical device design, the user experience is defined as *'the extent to which a device can be used by the intended user to achieve their specified goals with effectiveness, efficiency and satisfaction, in a specified context'* (Nagarajan *et al.*, 2020). This can be referred to as usability engineering, or human factors engineering (HFE), and acts as a means to recognise potential risks and hazards and achieve these goals (Shaheen *et al.*, 2021). This approach is crucial in identifying use-related errors at an early stage, which today remain a leading cause of device failure and recall (Shaheen *et al.*, 2021). A failure to address user needs during medical device design could cause the potential hazards associated with a device to outweigh its potential benefits, and undo the justification for that device (Shaheen *et al.*, 2021). Where user needs are not adequately addressed, such risks or hazards may be recognised after the device has gone into production, and could cause significant financial and reputational losses to the manufacturer (Stenberg *et al.*, 2017; Fisher and Johansen, 2020).

HFE has subsequently become commonplace for many medical device manufacturers, though recent reports and studies have suggested these analyses may be inherently biased against women and minority ethnic groups (Congenius, 2023; Davis, 2024; Johnson and Ensor, 2024). In cases where there are biases in a device, the manufacturer of that device cannot guarantee its effectiveness in certain user groups, and should this go undisclosed, clinicians and patients in that user group may unknowingly use an ineffective device (Davis, 2024). This contradicts the most fundamental principle of medical device design; to ensure a device is safe and effective in the intended user group. The World Health Organisation (WHO) supports this argument, estimating as much as 70% of the medical equipment that comes from the developed world is impractical for use in developing countries on account of inherent design biases (Vasan and Friend, 2020). Regardless, most medical imaging equipment used in developing countries has come from developed countries, perhaps without consideration for variations in demographic and contextual factors (Global Health, 2023). This research argues that incorporating users from diverse demographic backgrounds and contexts of use during the device design process could be pivotal in ensuring the device is safe and effective across populations. Some studies argue this would require multiple design variants, for example where the context of use varies significantly such as between developed and developing countries, or between urban and rural contexts (Kakati and Das, 2023). Ensuring a device is effectual across multiple contexts is particularly crucial where that device is used throughout the healthcare spectrum, such is the case with medical imaging.

CT scanners pervade the health spectrum with applications from trauma management to cancer diagnosis and monitoring, surgical planning, cardiac screening, interventional guidance, and more (Khan and Khan, 2023). However, these benefits remain unevenly spread with just 14% of developing countries reported to have one CT scanner per million inhabitants, compared with 100% of developed countries (Nigatu *et al.*, 2023). This significant imbalance has become known colloquially as *'the diagnostic divide',* and despite being a focus of researchers for several years now, biases within medical devices persist (Liu *et al.*, 2014; Ngoya *et al.*, 2016; Gwizdala, 2022; Sjoding *et al.*, 2022). In addition, much of the existing literature around medical device usability is focused on patients and healthcare professionals as a whole, with few studies targeting specific professional groups, for example radiographers (Bitkina *et al.*, 2020; Familoni and Babatunde, 2024).

Early studies on radiographers' experiences examine the physical exertion required to operate medical imaging equipment, while more recent studies appear focused on the mental load experienced by radiographers at work (Kumar *et al.*, 2003; Chinene *et al.*, 2023; Sipos *et al.*, 2024). A recent study carried out by Aldoihi and Hammami (2019), however, explores both the physical and mental strain on CT radiographers, ultimately encouraging CT system manufacturers to reduce their usability expectations and to incorporate features that can decrease this strain. The current research aims to complement this research with a specific comparative evaluation of the user experience in Ireland and in SSA, with regard to CT radiographers. This evaluation strives to identify discrepancies between the user groups and suggest region-specific design modifications to enhance the user experience and/or enhance access to CT imaging services in either region.

1.3. Research Objectives

The research aims to achieve the following objectives:

1. To examine the current status of CT imaging access in Ireland and in Sub-Saharan Africa
2. To examine the user experience of CT radiographers in Ireland and in Sub-Saharan Africa
3. To examine whether demographic and contextual factors may influence the user experience of CT radiographers
4. To provide recommendations to enhance the user experience of CT radiographers in Ireland and in SSA
5. To provide recommendations to improve access to CT imaging services in Ireland and in SSA

1.4. Dissertation Structure

This thesis is organised into six primary chapters:

Chapter 1: Introduction presents the research context and background, setting the stage for the subsequent chapters.

Chapter 2: Literature Review supports the present research and expands on the context provided in Chapter 1. This section examines the existing literature around the research topic and critically evaluates insights from several key sources to identify any trends or gaps in research, with a focus on CT imaging usability and accessibility.

Chapter 3: Methodology details the research design and the rationale behind the research methodologies used. This section briefly discusses the limitations encountered and the ethical considerations made during the research process. This section also introduces the data collection and analysis methodologies.

Chapter 4: Results and Analysis presents the research findings and identifies any patterns or themes that emerged from the data. This section employs various data visualisation techniques to clearly present the data and provides a brief analysis of the results before discussing the findings in depth in the following chapter.

Chapter 5: Discussion interprets and analyses the data presented in Chapter 4 in depth, explaining their significance and relating them to the literature presented in Chapter 2 and otherwise. This section discusses the study limitations in depth, as well as the potential implications of the study, and provides recommendations to enhance CT system usability and accessibility in both regions. Recommendations for future research are also provided in this section.

Chapter 6: Conclusion summarises the key findings of the research with reference to the primary and secondary research objectives.

Chapter 2: Literature Review

This section examines existing literature around the research topic to establish the landscape of CT system design and usability, as well as access to CT imaging services in developed and developing regions, with specific reference to Ireland and SSA.

2.1. Introduction to Secondary Research

In recent years, biases in medical device design have revealed a profound exclusion of minority ethnic groups and other commonly marginalised communities (Davis, 2024; Johnson and Ensor, 2024). This research seeks to examine these biases and examine how this exclusion could be impacting CT system usability and accessibility in developing regions, whose inhabitants are often under-represented in the medical device industry (de Kanter *et al.*, 2023). This research examines HFE in medical device design and typical inclusion criteria for participant studies, while assessing the impact excluding certain demographic characteristics could have on medical device operation and usability. The research seeks to address gaps in literature around the importance of including a diverse range of demographic and contextual factors when designing complex medical imaging equipment, such as CT scanners. Through this, the research seeks to address the chronic shortage and under-use of medical imaging equipment across Sub-Saharan Africa (SSA), imagining enhancing CT system usability and accessibility could help to resolve these issues. In a broader context, this research advocates for inclusivity in medical device technology, and provides insights into the occupational experience of radiographer, who remain an under-represented profession in literature (Foley *et al.*, 2020).

Several key words and phrases were identified during the development of this chapter, namely: human factors engineering, medical device design, user need, usability, accessibility, biases in device design, inclusion and diversity, computed tomography, and radiographers. These terms were repeatedly inserted into multiple search engines such as Google and Google Scholar, and several academic databases such as PubMed, ScienceDirect and EBSCO, the latter accessed via the Griffith College Library. Cited publications are recent and peer-reviewed, with some older resources included on account of their unique value-add.

2.2. The Role of Computed Tomography in Modern Healthcare

Since its inception over 50 years ago, computed tomography continues to revolutionise healthcare today (Koo *et al.*, 2017; Mshnail *et al.*, 2023). The advanced medical imaging technique combines traditional x-rays with complex computer algorithms to produce detailed, cross-sectional images of the internal structures of the human anatomy (Aldoihi and Hammami, 2019). This has enabled physicians to diagnose medical conditions at an earlier stage, plan treatments and monitor the progress of medical interventions (Khan *et al.*, 2023). CT scanners typically comprise an x-ray source and detector assembly which rotate in tandem around the patient, as shown in Figure 1 (Garnett, 2020).

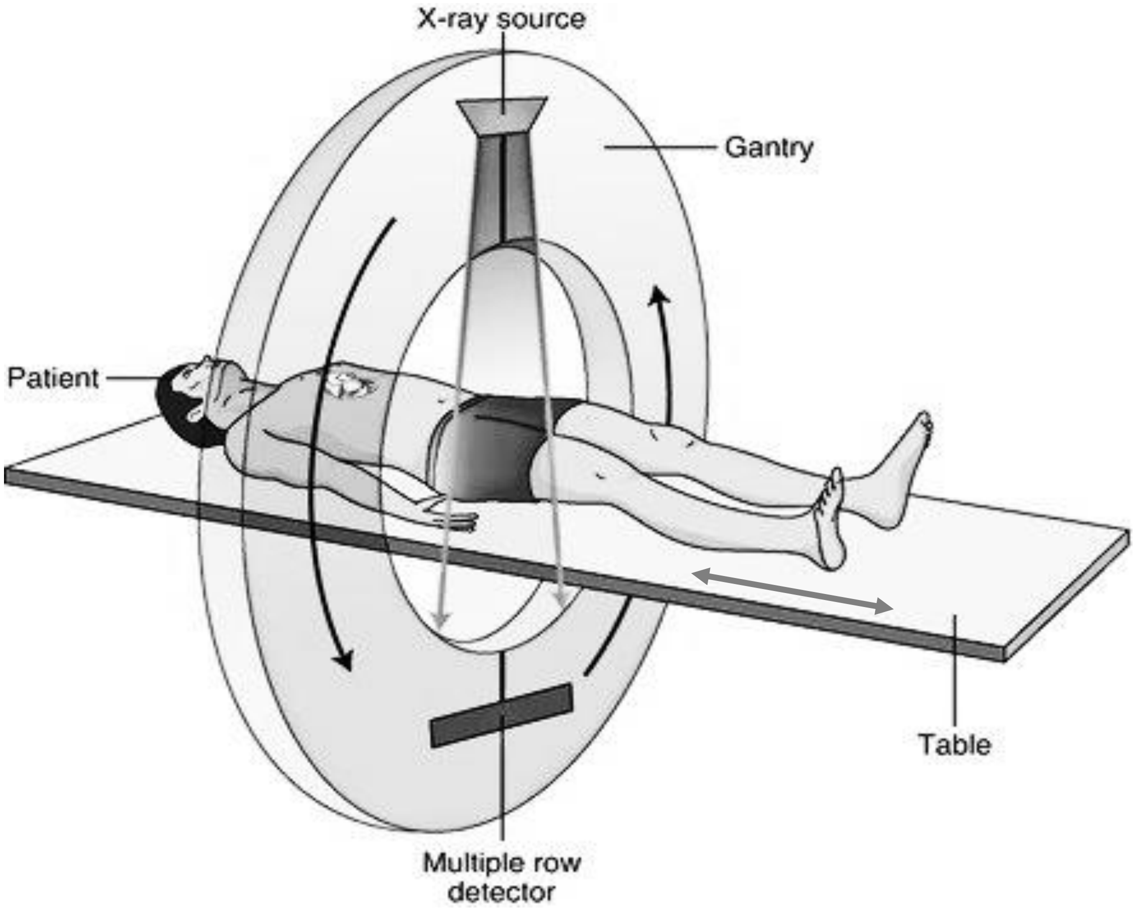

Figure 1 CT Scanner Diagram (Garnett, 2020)

Figure 1 depicts a simplified diagram of a modern CT scanner, the patient lying supine on the scan table, the x-ray source/x-ray tube and multiple row detector rotating around the patient, through 360^{0}, as the scan table moves through the CT scanner gantry. This synchronised movement enables comprehensive imaging of the internal anatomical structures from multiple angles, facilitating detailed diagnostic assessment.

2.2.1. Clinical Applications of CT

CT is described as a powerful advanced imaging technique with applications across the entire health spectrum, from neurology to cardiology, respiratory, gastrointestinal, and many more (Pape *et al.*, 2022; Khan and Khan, 2023; Poyiadji *et al.*, 2023). CT also has widespread application in emergency medicine, largely due to its rapid acquisition time when compared with other advanced imaging technologies such as MRI. This enables prompt diagnosis and intervention in time-sensitive cases which can reduce the rates of morbidity and mortality (Imai *et al.*, 2018; Driban *et al.*, 2023). CT systems, however, can sometimes be over-used on account of their broad applications and ready availability compared with other advanced imaging technologies (Baloescu, 2018; Umar and Khan, 2023). However, this ready availability (in developed regions) is also responsible for reducing the rate of emergency surgeries by 5-13%, the significance of which cannot be understated as emergency surgeries are associated with a greater risk of post-operative complications. These include surgical site infection, hospital acquired pneumonia, sepsis, and pulmonary emboli (PE) (Power *et al.*, 2016). In addition, CT plays a crucial role in diagnosing and managing many sub-acute and chronic conditions, including cancers and associated complications.

Cancer remains a leading cause of death and disability in developed regions, its incidence rising in developing regions due to worsening environmental conditions and an ageing population, as well as the adoption of western lifestyles (You and Henneberg, 2017). CT scans play a crucial role in diagnosing, monitoring and treating oncological conditions, including their complications e.g., haemorrhage and vessel thrombosis (Bansal *et al.*, 2023). CT subsequently remains the most commonly performed imaging modality in patients with cancer, while also playing a role in cancer screening as some studies suggest low-dose CT screening could actually reduce cancer incidence (Tang *et al.*, 2019; Shu and Jin, 2023). While cancer remains a leading cause of death in many regions, the absolute most common cause remains cardiovascular disease, in which CT scans also play an immediate role (You and Henneberg, 2017). CT imaging can help diagnose and monitor various cardiovascular conditions and can provide pre-procedural planning, for example before an aortic valve replacement (Nazir and Nicol, 2019). CT can provide multi-planar reconstructions (MPRs) which depict anatomy in various planes, and can also provide 3D image reconstructions which can help surgeons to better visualise anatomy and plan their interventions, minimising room for error (Khan and Khan, 2023).

3D image reconstruction also remains commonplace for many orthopaedic applications, enabling detailed fracture assessment which allows the surgeon to carefully tailor their surgical intervention to the patient's unique anatomy (Patel *et al.*, 2023). CT also plays a role in post-operative and even intra-operative management, providing real-time guidance during interventional procedures such as biopsies, drainages and radio-frequency ablations (Khan and Khan, 2023). Through this, the radiologist can more accurately guide their device, whether that is a biopsy needle, drainage catheter, or ablation probe (Khan and Khan, 2023). This minimises the risk of intraoperative and post-operative complication, while aiding procedural efficiency. Guiding interventions with CT, rather than ultrasound or traditional x-ray fluoroscopy, can provide several benefits such as superior deep tissue visualisation and immediate, detailed post-operative assessment. This often makes CT the preferred choice for many interventional radiologists (Sulieman and Alkhorayef, 2019).

In addition, CT scans remain the initial study of choice for evaluating suspect stroke, even though MRI can typically provide greater detail (Shafaat and Sotoudeh, 2024). Again, this is because CT scans are typically more accessible and can be produced with rapid speed (Umar and Khan, 2023; Shafaat and Sotoudeh, 2024). The primary concern with CT is the relatively high radiation burden when compared with traditional x-ray, ultrasound (US), MRI and other imaging techniques (Kazemi *et al.*, 2023). Many researchers have even documented concern around the appropriateness of radiation doses delivered through CT, as determined by the radiographer (Muhogora *et al.*, 2010; Mahmoudi *et al.*, 2019; Paolicchi *et al.*, 2020; Dane *et al.*, 2021; Al-Hayek *et al.*, 2024). To ensure CT scans will deliver a net benefit, they must continue to outweigh the potential risks, achieving images with a radiation dose that is as low as reasonably achievable (ALARA) (Mahmoudi *et al.*, 2019).

2.2.2. Impact of CT Imaging on Healthcare Systems

CT imaging has been shown to improve patient outcomes by speeding up diagnoses and enabling more timely interventions which can be useful both in communicable and non-communicable disease (Khan and Khan, 2023). This has helped to reduce hospital admissions, as well as reducing the length of hospital stays, and can decrease the burden on healthcare systems, financially and operationally (Pillay *et al.*, 2023). This can be transformative given that many health systems around the world experience chronic strain, including those in Ireland, where a recent hiring embargo has compounded the chronic shortage of health professionals (Cullinane, 2024). This has led to CT waiting lists being cancelled as health facilities manage staff shortages, and could risk increasing burnout among radiographers which remains an established sentiment in the profession (Singh *et al.*, 2017; Foley *et al.*, 2020; Burns, 2024; Sipos *et al.*, 2024). Chronic staff shortages are also prevalent in SSA, where the ratio of radiographer to population in many countries is 32 times greater than the same ratio in Ireland (Kawooya *et al.*, 2022; CORU, 2023; Worldometer, 2024).

CT imaging services can also place less demand on financial and infrastructural resources when compared with other advanced imaging techniques such as MRI (Baloescu, 2018; Heye et al., 2020). This is a crucial consideration for developing regions where funding is of principal concern, and infrastructural resources are limited, meaning the enhancement of CT services may be more feasible than other techniques while infrastructural resources remain limited. For example, CT imaging services typically demand less from electrical resources than MRI, despite being used more frequently (Heye *et al.*, 2020). For example, one CT scan consumes approximately 20 times less energy than one MRI scan, on average (Heye et al., 2020). Substantial energy consumption, and its financial implications, among several other factors explain the abundance of advanced imaging technologies in developed regions when compared to developing regions (Hilabi et al., 2023; Hinrichs-Krapels et al., 2023). One must remain aware, however, that enhancing CT services cannot replace the need to improve access to MRI, both services offering unique benefits. It should also be noted that some manufacturers have started to develop more sustainable solutions to reduce the energy consumption of MRI, although these solutions are still more energy-intensive than CT (Siemens Healthcare Ltd., 2024).

In financial terms, CT scans can help reduce the length of hospital stays, reducing the overall hospital spend and increasing hospital profitability. This may be of significance to non-governmental organisations (NGOs) who operate in developing countries to improve health services and commonly perceive medical imaging services as supplemental (Jiang *et al.*, 2014; Imai *et al.*, 2018; Frija *et al.*, 2021). One should note that improving access to CT imaging services could help to release hospital beds, reducing the financial burden associated with patient admissions, and indirectly releasing capital for re-direction into hospital services deemed more urgent by NGOs, for example.

2.3. Access to Computed Tomography: Global Perspectives

CT imaging services continue to experience increasing demand while access to these services remains limited in many developing countries (Vasan and Friend, 2020; TechSci Research, 2023; Khan *et al.*, 2023). An estimated 80% of our global population lives in developing countries while just 14% of these countries have one CT scanner per million inhabitants (UNCTAD, 2022; Nigatu *et al.*, 2023).

2.3.1. Global Statistics on CT Imaging Access and Utilisation

The WHO recommends countries have at least twenty radiography units per one million inhabitants, whether these are CT scanners, MRI scanners, general x-ray equipment, US and so on (Ngoya *et al.*, 2016). While developed countries typically meet this standard, with almost 40 CT scanners alone per million inhabitants in many high income countries, there is often less than one CT scanner per million inhabitants in developing countries, as mentioned (Frija *et al.*, 2021). This discrepancy is typically less pronounced with basic imaging equipment such as x-ray and US machines, and more pronounced with advanced imaging equipment such as CT, MRI and nuclear medicine scanners, meaning people in developed countries can benefit from superior diagnostic accuracy when compared with those in developing countries (Frija *et al.*, 2021). Similar divides exist between public and private healthcare facilities, where medical imaging equipment is concentrated in private facilities, as is the case in Uganda (Kiguli-Malwadde *et al.*, 2020). In addition, many countries have inherent inequities between urban and rural healthcare, with those in urban areas benefiting from enhanced services. This may force those living in rural to travel long distances to receive adequate imaging, for example, by which time their condition may have deteriorated (Kawooya, 2012). Despite this, the development of diagnostics in medical device technology continues its focus in developed regions (Vasan and Friend, 2020; Hirschfelder, 2021).

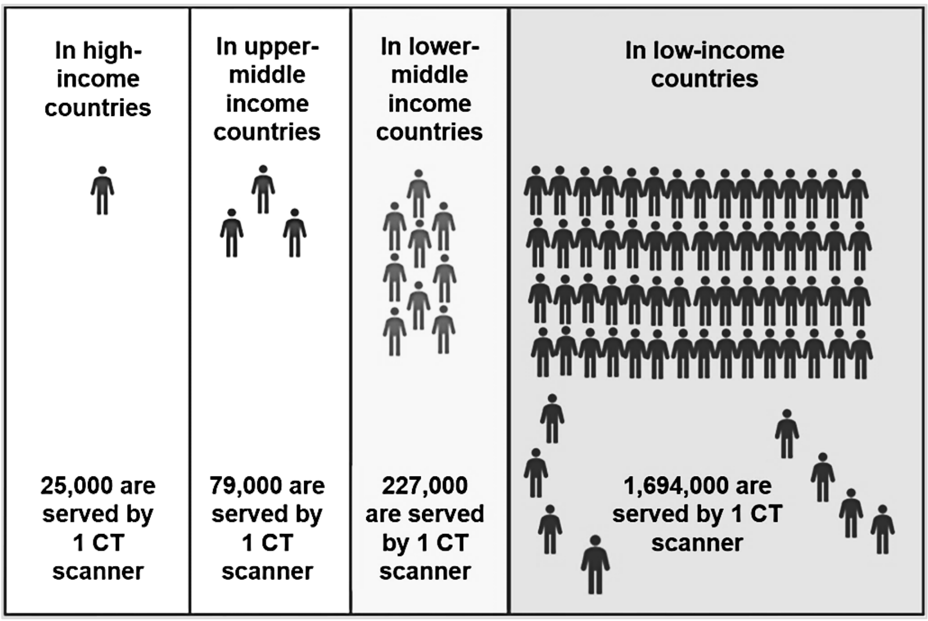

Figure 2 depicts disparities in access to CT scanners around the world. Ireland falls between the upper-middle and high-income countries brackets, while most countries of SSA fall into the low-income countries bracket.

Figure 2: CT System Ratio to Global Population (Hirschfelder, 2021)

2.3.2. Global Barriers to CT Access

Despite its many advantages, CT faces several barriers in developed and developing countries (Liu *et al.*, 2014; Frija *et al.*, 2021). These can be defined as obstacles or challenges that impede the implementation of, access to, or utilisation of CT imaging services. In developed countries, CT access barriers typically pertain to healthcare professional shortages, while those in developing countries are often more complex, relating to infrastructural challenges, equipment and consumable shortages, suboptimal equipment maintenance, healthcare professional shortages, and limited integration and support (Hinrichs-Krapels *et al.*, 2023). The present research examines each of these barriers, while investigating a potential fifth barrier: the exclusion of demographic and contextual factors during CT system design.

Enhancing imaging services often relies on infrastructural soundness, extending to include electrical and internet supplies, some researchers suggesting the development of less advanced medical imaging technologies specific to resource-limited regions (Ogbole, 2022; Anazodo *et al.*, 2022). Their theory suggests the development of medical imaging equipment that offers basic diagnostic capabilities, favourable over no equipment at all, and refers specifically to MRI service enhancement in Africa (Ogbole, 2022). However, the present research theorises that similar principles can be applied to enhancing CT imaging services. Some imaging equipment manufacturers, however, remain reluctant to invest in solutions for developing countries, one product specialist arguing the demand is too unpredictable in Africa, specifically (Global Health, 2023). This argument, however, contradicts the core belief that access to quality healthcare should be equitable, leaving patients in developing countries to receive suboptimal care (Ngoya *et al.*, 2016; Brady *et al.*, 2020). Several researchers have conceptualised ideas to overcome the infrastructural barriers in developing countries, however, this would require the support of large multi-national corporations and governmental organisations (Liu *et al.*, 2014; Ng'andwe and Bwanga, 2022; Aderinto, 2023).

Another reported access barriers includes machine maintenance and servicing challenges, these required to maintain the functionality and diagnostic accuracy of medical imaging equipment (Hinrichs-Krapels *et al.*, 2023). Many developing regions, however, suffer a shortage of service engineers to perform these tasks, many sufficiently trained individuals opting to emigrate in search of better working conditions and pay opportunities (Mishra, 2023). To ensure CT systems can function without unprecedented failures which could result in scan cancellations, poor patient outcomes, and even lost revenue, preventative maintenance should be regularly carried out (Adem *et al.*, 2023). This is arguably more important in regions where CT imaging systems are in a refurbished condition, as is commonly the case for developing countries (Global Health, 2023). Such refurbished equipment may be more challenging to maintain, and some service engineers may even refuse to maintain it once it has been removed from the purchasing loop (Global Health, 2023). Nonetheless, attempts at resolving the diagnostic divide with refurbished CT scanners have persisted for decades (United States Congress, 1981). Recent reports have asked manufacturers to enhance their resolution strategies by acknowledging and responding to the needs of the intended user, rather than continuing to drive solutions that have not majorly impacted the diagnostic divide (Shaheen *et al.*, 2021).

These barriers are intensified by a sustained shortage of radiographers to operate medical imaging equipment, and radiologists to report on images produced, as each year, many healthcare professionals emigrate from developed and developing countries through a phenomenon known as *'brain drain'* (Ujumadu, 2021; Sibiya *et al.*, 2022; Hinrichs-Krapels *et al.*, 2023; Ghlionn, 2024). For example, in Nigeria, one of Africa's largest health economies, as many as five radiographers reportedly emigrate every week in pursuit of better working conditions (Ujumadu, 2021). The radiographers who do remain in their countries are often based in urban areas, leaving remote regions largely under-resourced, despite the majority of the SSA population living in rural areas (Kawooya *et al.*, 2022; Ng'andwe and Bwanga, 2022).

2.3.3. Global Case Studies

A report from Ireland expressed the importance of CT imaging in maintaining a health service, describing the impact reduced access to CT imaging services has had on their facility (Reilly, 2023). A spokesperson for the hospital agued the lack of CT scanning capacity may have a detrimental impact on patient care, such as delayed cancer diagnoses, as delays in receiving CT scans and CT-guided biopsies persist. The hospital, which has one CT scanner on site, reported difficulties where preventative maintenance procedures are performed or where their scanner breaks down, as they have no alternative scanner (Reilly, 2023). This has meant emergency cases must be transferred to external hospital sites, which can incur greater costs and place patients at heightened clinical risk (Reilly, 2023). Similar situations have been reported in other developed countries, including in Canada, where insufficient CT scanning capacity in rural areas means patients frequently require costly inter-facility transfers which can delay diagnosis and treatment (Bergeron *et al.*, 2017). This facility had no CT scanner on site, despite Canada reportedly having one of the best health services in the world (Statista, 2024). In South Africa, a developing country whose health service is typically ranked lower than that of Ireland and Canada, a gross insufficiency of CT imaging services has also recently been reported (Pongweni, 2024).

A large hospital in South Africa has allegedly seen delayed diagnoses and treatment due to reduced CT scanning capacity, with one report claiming individuals have died as a result (Pongweni, 2024). Dr. George Mukhari Academic Hospital in Ga-Rankuwa, South Africa reportedly had three CT scanners in 2023, two of which were older, and the third was supplemental as it could not handle a heavy workload (Pongweni, 2024). The older CT scanners reportedly ceased to function in the second half of 2023, and the third scanner stopped working in early 2024. Pongweni (2024) claims a significant number of patients have endured suffering and even death as physicians were forced to diagnose and treat patients without crucial information that would typically have been gathered through CT imaging (Pongweni, 2024). This tragic case study stresses the importance of CT imaging in maintaining a functional health service, and the urgent need to enhance CT imaging services in Africa.

2.4. Radiographers' Roles and Responsibilities in CT Scanning

Since its introduction, CT imaging services have continued to advance in complexity, the progression of which would not be possible without radiographers, the operator and the primary user of CT imaging systems (Mahmoudi *et al.*, 2019). Radiographers are also commonly referred to as radiographic technicians or radiologic technologists, depending on the country in which they practise (Mahmoudi *et al.*, 2019).

2.4.1. Radiographers' Training and Educational Requirements

Training and educational requirements for radiographers vary significantly between countries, both in terms of duration and quality (Foley *et al.*, 2022). In Uzbekistan, a developing country, only one month of training is required to receive qualification, while in Ireland, four years are required (Foley *et al.*, 2022). Educational requirements in South Africa and other SSA countries typically follow western models, requiring between four and five years of training (van de Venter and Engel-Hills, 2022; JKUAT, 2023; Money, 2023). In the US, radiographers must complete additional certification before becoming a

CT technologist or CT radiographer (Snyder, 2016). Such additional certification is optional in Ireland as many radiographers practise in CT without receiving a formal CT education (UCD, 2024). Perhaps consideration should be given to the varying educational experiences between radiographers in different regions when designing medical imaging technologies. Regardless, CT systems appear to be continually advancing in complexity with one study estimating the performance of CT systems doubles in every two years (Aldoihi and Hammami, 2019). Aldoihi and Hammami (2019) suggest the cognitive load on radiographers also continues to rise, perhaps related to the increasing performance of their scanners (Aldoihi and Hammami, 2019; McNulty *et al.*, 2021; Foley *et al.*, 2022).

2.4.2. Professional Development and Continuing Education

Education has an undeniably profound impact on the knowledge of radiographers, and researchers worldwide have expressed concern around the knowledge of radiographers regarding radiation exposures in CT. Ensuring the mental load on radiographers is not excessive is pivotal considering the significant source of radiation exposure that is CT imaging, delivering approximately 50% of radiation exposures delivered in healthcare (Muhogora *et al.*, 2010; Kazemi *et al.*, 2023; Al-Hayek *et al.*, 2024). Several studies report inadequate knowledge of exposure parameters among radiographers and radiography students, indicating the growing cognitive load on radiographers may be too demanding among their several other tasks (Mahmoudi *et al.*, 2019; Paolicchi *et al.*, 2020). Some researchers have suggested a review of educational materials or mandatory continued training courses as a means to resolve this issue (Mahmoudi *et al.*, 2019; Kada, 2020; Paolicchi *et al.*, 2020), while others acknowledge the significant cognitive load on CT radiographers, suggesting automated measures could assist in alleviating occupational pressures (Toshiba, 2014; Dane *et al.*, 2021).

In addition to this, access to continued education can be limited in many developing countries, for example, continued professional development (CPD) programs are typically not endorsed in SSA (Ng'andwe and Bwanga, 2022). Contrastingly, radiographers in Ireland are required to complete several CPD courses within a 12-month period, and to maintain a personal CPD portfolio (CORU, 2024). This ensures radiographers in Ireland continually broaden their knowledge base, and encourages self-assessment and accountability (Wareing et al., 2017). Where advanced learning is not typical, perhaps CT system manufacturers should not encourage scanners with novel technologies, unless adequate training and support is provided.

2.4.3. Scope of Practice in CT Scanning

CT scanning tasks are diverse and require a broad range of skills and expertise. In a single day, a CT radiographer could perform a CT brain on an ambulatory patient in otherwise good health, a multi-phase contrast-enhanced CT study on a ventilated patient from the intensive care unit (ICU), and an ultra-low-dose CT thorax on an uncooperative neonate (Tschauner *et al.*, 2021). That same day, the radiographer might be expected to guide cardiac catheterisation procedures and orthopaedic interventions in other departments, responsible for the delivery of relatively high radiation doses (Muhogora et al., 2010; Kazemi et al., 2023). Where these contextual factors are not thoroughly considered during device design, CT radiographers may become reluctant to use certain equipment through fear of erroneously delivering excessive radiation doses. This could explain why in SSA, where a chronic shortage of medical imaging equipment persists, some operational equipment sits idle (Aderinto, 2023). However, this may also be because much of their medical imaging equipment comes from the developed world, perhaps without consideration for their unique demographic and contextual characteristics (Kiguli-Malwadde et al., 2020).

CT system operation requires the radiographer to perform several tasks, from patient care to scan preparation, protocol selection, exposure parameter determination, and scan execution (Mahmoudi *et al.*, 2019). In many cases, CT radiographers are also expected to produce image reconstructions and sometimes perform basic quality assurance (QA) procedures. The present research considers CT system operation in three distinct phases: pre-scanning, scanning, and post-scanning. This always begins with patient care as the CT radiographer prepares and positions the patient on the scan table. This step requires the radiographer to interact with the various scanner gantry controls, as shown in Figure 3 (Canon Medical Systems, 2024). Recently, some CT system manufacturers have introduced automated patient positioning cameras with an aim to ensure more consistent patient positioning, and avoid excessive or insufficient radiation exposures to the patient (Salimi *et al.*, 2023; Al-Hayek *et al.*, 2024).

Once the patient is positioned, the radiographer consults the CT system user interface to select the patient's personal information and ensure their images go into their correct file (Figure 4) (Medical Imaging Education, 2024). Ensuring ease of operation at this stage is vital to avoid identification errors which could lead the patient to receive inappropriate treatment and in some cases, even unnecessary or inappropriate surgical procedures

(Woodward *et al.*, 2022; Spacey *et al.*, 2024). Once the patient's correct information has been selected, the radiographer selected their desired procedure protocol, some systems equipped with pre-defined protocols which contain typical exposure factors for common CT procedures e.g., CT brain and CT pulmonary angiogram (Foley *et al.*, 2012a). Pre-defined protocols, however, are not exhaustive and radiographers must use their technical knowledge to tailor exposure parameters such as kilovoltage (kV), milliamperes (mA), exposure time (s), pitch, and slice thickness (mm) on a patient-by-patient basis (Mahmoudi *et al.*, 2019). Incorrect parameter selection can lead to excessive or insufficient radiation doses, most CT systems incorporating automatic exposure control capabilities to assist radiographers in making this selection. In CT, this is known as dose modulation (Inoue *et al.*, 2018).

Figure 3 CT Scanner Gantry Controls Canon Medical Manufacturer (Canon Medical Systems, 2024)

Figure 3 depicts a CT scanner gantry and associated controls that the radiographer uses to operate the physical components of the CT scanner such as the patient table and scanner laser lights. The configuration of these controls varies between CT system manufacturers.

Ensuring ease of interaction with the CT system user interface is crucial considering the pressures many radiographers face to perform multiple scans in quick succession (Dane *et al.*, 2021). Radiographers should be empowered to easily identify and rectify errors, whether through interaction with the scanner hardware or software component. Once the radiographer has approved their scan plan, they will initiate the scan using either the user interface or control panel buttons, depending on the manufacturer (Figure 5) (Richardson Electronics, 2020). Navigating the various on-screen options and/or control panel buttons should be easy and ergonomically sound, especially considering the potential time pressures.

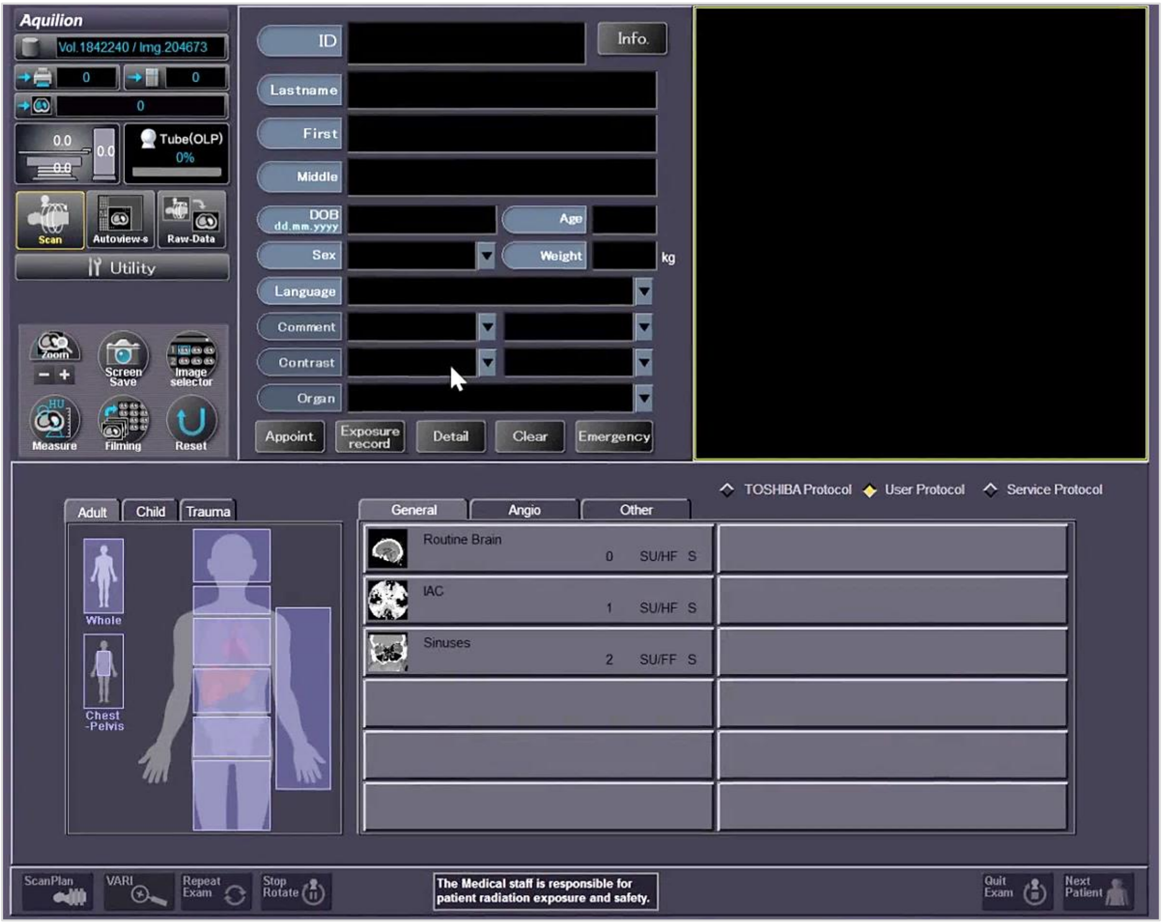

Figure 4: CT Scanner User-Interface Canon Medical Manufacturer (Medical Imaging Education, 2024)

Figure 4 depicts a typical CT system user interface. Radiographers use this page to perform several tasks such as selecting patient information and CT procedure protocols. The user interface configuration, layout and terminology varies widely between manufacturers.

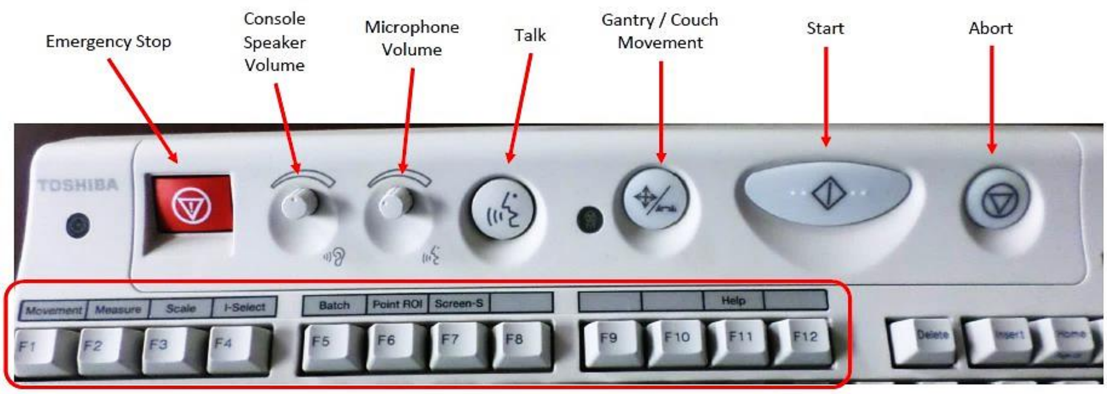

Figure 5 Control Panel Buttons Canon Medical Manufacturer (Richardson Electronics, 2020)

Figure 5 depicts a typical CT system control panel with which the radiographer may initiate or abort the CT scan, for example. The radiographer can typically verbally interact with the patient using these controls and make patient table and/or gantry movements.

Once the CT scan is complete, the radiographer will again interact with the system user interface to produce or trigger the required image reconstructions e.g., MPRs or 3D images (Figure 6) (Taverna *et al.*, 2017). These post-scanning tasks can compound the growing mental load on CT radiographers, the future of image reconstruction expected to further increase in complexity (Blum *et al.*, 2020). Consideration for the growing mental burden on radiographers should be paid to avoid increasing the incidence of use-related error (Shaheen *et al.*, 2021).

Figure 6 demonstrates CT image reconstructions, including sagittal (top left), axial (top right), coronal (bottom left) and 3D/volume rendering (bottom right). This patient has fractured their scapula.

Visualisation of the anatomy in multiple planes allows for a more thorough assessment of the injury and its association with surrounding structures, enhancing diagnosis and management of the injury.

Figure 6 CT Image Reconstructions (Taverna et al., 2017)

2.5. CT Access in Developed Countries: Ireland as a Case Study

The WHO recommends that each country has at least 20 radiography units per million inhabitants (Ngoya *et al.*, 2016)

2.5.1. Current State of CT Access in Ireland

Ireland currently surpasses this recommendation with 20.3 CT scanners alone per one million inhabitants, the majority of which (70%) reportedly belong to the public sector, while approximately 30% belong to the private sector (Foley *et al.*, 2012b; Murphy and Kelly, 2023). In 2012, Foley *et al.* (2012b) described Irish CT scanner distribution, reporting most diagnostic imaging services had only one CT scanner, two participating centres reported to have two CT scanners. Since their study took place, CT scan demand and the population of Ireland have both continued to increase (Thurley *et al.*, 2018; Maskell, 2022; CSO, 2024). The Medical Exposure Radiation Unit (MERU) (2017) also reports a 90% increase in CT scans performed between 2010 and 2016, indicating the cumulative demand on radiographers in Ireland and on their scanners may have increased disproportionately in the last decade.

2.5.2. Government Policies and Healthcare Initiatives

In Ireland, the national health service aims to see patients within six hours of arrival in the emergency department (HSE, 2024c). However, reports found that patients who needed a CT scan experienced an average wait six hours longer than patients who did not (Griffin, 2023). The wait time for outpatient appointments has also increased, with many patients waiting over a year for their CT scan appointment (Kent, 2024). In an attempt to expedite access to imaging, general practitioners (GPs) were recently given direct access to radiology services and while this has improved access, waiting lists for CT scans remain excessive and are expected to worsen as this initiative shortly comes to an end (Cullen, 2023; Phelan *et al.*, 2023; Kent, 2024).

Scan availability is further restricted in Ireland due to staff shortages resulting from the recent hiring embargo (Cullinane, 2024). This meant that new radiography graduates and unemployed radiographers struggled to find employment in the public radiography services, further exacerbating their chronic staffing issues and potentially exacerbating brain drain. This also meant radiographers who were employed in the public sector could have experienced symptoms of burnout and mental exhaustion, as reported during other challenging periods such as the Covid-19 pandemic (Aldoihi and Hammami, 2019; Foley et al., 2020; Cullinane, 2024).

2.5.3. Challenges Facing Radiographers and Patients in Ireland

As CT scan waiting lists continue to increase, patients may become anxious as their diagnoses could be delayed, as well as their prospective treatment (Reilly, 2023). To avoid worsening patient conditions, CT scan access must be improved (Cullinane, 2024). As mentioned, CT access barriers in Ireland are typically associated with staff shortages and subsequent service limitations (Murphy and Kelly, 2023; Kent, 2024). Identifying ways to enhance access to CT could alleviate some of the systemic pressures and reduce the physical and mental strain on CT radiographers (CSJ, 2024). In Galway, one of Ireland's largest cities, radiographers have even called for industrial action due to ongoing staff shortages (O'Donovan, 2023).

Radiographers in Ireland have reported frustration amid a common exclusion from the decision making process in healthcare, their services an apparent afterthought (Foley *et al.*, 2020). This was highlighted during the Covid-19 pandemic, as radiographers expressed feelings of under-appreciation and exclusion, these factors considered contributory to their resignation, similar to observations made in Ghana and Zimbabwe in other challenging periods (Ashong *et al.*, 2016; Foley *et al.*, 2020; Hinrichs-Krapels *et al.*, 2023). In 2020, Foley *et al.* (2020) called for attention to radiographers' mental health and burnout, these factors likely to persist were staff shortages to continue to worsen (Foley *et al.*, 2020; Maskell, 2022). In addition to this, Ireland faces the same issue as many other countries where most CT scanners are concentrated in urban areas, forcing patients in rural areas to travel to access services (Nixon et al., 2014; Google Maps, 2024; Pan et al., 2024). In Ireland, there are community care services offering patient transportation to and from certain hospitals. However, these services are dependent on the patient's home address and the facility in which their appointment is based and therefore remain limited (CIC, 2024).

2.6. CT Access in Developing Countries: Sub-Saharan Africa as a Case Study

Those in developing countries endure a chronic shortage of medical imaging equipment and healthcare professionals, as well as limited healthcare infrastructure to support the enhancement of these services (Kiguli-Malwadde *et al.*, 2020; Kawooya *et al.*, 2022).

2.6.1. Current State of CT Access in Sub-Saharan Africa

Most countries in SSA do not meet the 20 radiography units per one million inhabitants as recommended by the WHO (Ngoya *et al.*, 2016; Nigatu *et al.*, 2023). In 2016, Ngoya *et al.* (2016) performed an audit on the state of medical imaging equipment in Tanzania, and reported just 5.7 radiography units per million inhabitants in the public sector, and 21 times fewer CT scanners per million inhabitants than that of neighbouring South Africa. Their study highlights one of the most prominent issues in healthcare across SSA, a significant proportion of medical imaging services and training institutions are run privately, catering only to the wealthier populations (Kawooya *et al.*, 2022). While private services are also present in Ireland, most of the country's medical imaging equipment remains in public facilities (Foley *et al.*, 2012b). In Africa, advocates have asked government institutions to facilitate public-private partnerships to enable the delivery of advanced imaging services to the wider population (Kawooya *et al.*, 2022). Without this collaboration, many public facilities may not be able to afford the costs associated with high-tech medical imaging equipment and its maintenance, and may be unable to repair or replace dysfunctional CT scanners (Aderinto, 2023).

In SSA, the functional radiography units are typically concentrated in urban areas, as in Ireland, forcing rural populations to travel long distances to access CT imaging services, placing their health at increased risk (Kawooya, 2012). The ratio of CT scanners to one million inhabitants in the Democratic Republic of Congo (DRC) is 0.07, in Kenya is 1.49 and in Tanzania is 0.8, compared with 20.3 CT scanners per million inhabitants in Ireland (Mutala *et al.*, 2020; WHO, 2024; Muthinji, 2024). In Africa's largest economy, South Africa, there is approximately 1.7 CT scanners per million inhabitants (WHO, 2024; Muthinji, 2024). This limited imaging equipment across the SSA region means patients must travel long distances to access CT imaging services, if accessible at all (Aderinto, 2023). Unequal distribution of medical imaging equipment is a common issue in Ireland and SSA, however, the distance between CT imaging services is far less in Ireland than it is in SSA (Okiro and Ouma, 2018). This is crucial as Okiro and Ouma (2018) argue almost 50% of deaths and 75% of disabilities can be avoided with enhanced access to emergency care. Medical imaging services play a vital role in the provision of emergency care, with CT regarded as the most valuable imaging tool in trauma management (Nuñez *et al.*, 2002; Fathi *et al.*, 2024). However, to enhance these services, infrastructural issues would need to be addressed and governmental and non-governmental support would be required.

A simple but impactful reason for the shortage of medical imaging equipment across SSA is its associated financial burden, whether when purchasing or maintaining the equipment (Aderinto, 2023). Limited access to CT in SSA, however, is also heavily influenced by lacking infrastructure, consumables, and a chronic shortage of healthcare professionals, as mentioned (Kawooya *et al.*, 2022; Hinrichs-Krapels *et al.*, 2023). The current research examines the potential contribution of demographic and contextual factors to CT system usability and accessibility challenges.

2.6.2. Barriers to CT Access in Sub-Saharan Africa

In many SSA countries, the implementation of medical imaging services is inhibited by unstable electrical and internet connections, as some authors suggest the development of somewhat less technical equipment could help enhance imaging services in developing regions (Ogbole, 2022; Anazodo *et al.*, 2022). Anazodo *et al.* (2022) have explored this concept, supporting the argument made by Dr. Godwin Ogbole, an inspirational scholar and radiology professor. This argument suggests the development of less advanced, less expensive imaging equipment that offers basic diagnostic capabilities as a means of increasing the abundance of medical imaging equipment in developing regions, and reducing the diagnostic divide (Ogbole, 2022). The theory pertains specifically to improving MRI services across Africa, while the enhancement of CT imaging services is theoretically less challenging.

SSA also faces a chronic shortage of medical imaging professionals to operate the equipment, and biomedical professionals and service engineers to maintain and test the equipment, threatening the prosperity of medical imaging services in SSA (Adem *et al.*, 2023). Adem et al. (2023) performed an assessment of medical imaging equipment downtimes across Ghana, concluding that these were often frequent and lengthy, and a threat to public health, also concluding that significant losses in revenue were incurred by the healthcare facility during machine downtimes. Perhaps less complex imaging solutions that are more robust could help to alleviate this issue, and avoid lost revenue in countries where financial resources are scarce (Adem *et al.*, 2023). As brain drain also affects the abundance of radiologists in the region, some organisations have started training radiographers to interpret and report on medical images, as well as produce them, further increasing their overall mental load (Kawooya, 2012). Perhaps image interpretation assistance and remote operation could release the strain on CT radiographers in regions where such initiatives are taking place (Frija *et al.*, 2021).

Implementing advanced features, however, cannot be achieved without increased system integration and support (Global Health, 2023). Unfortunately, as large multi-national corporations and NGOs continue to undervalue the importance of enhancing CT services, healthcare facilities and patients are left to contend with sub-optimal care and a poorer quality health service when compared with that of developed regions (Ngoya *et al.*, 2016; Brady *et al.*, 2020; Global Health, 2023). This lack of support further complicates efforts to enhance CT imaging services, the present research striving to advocate for increased support. Several solutions have been conceptualised to address some of the discussed access barriers, however, the diagnostic divide remains to be resolved (Liu et al., 2014; Ng'andwe and Bwanga, 2022; Aderinto, 2023).

2.6.3. CT Access Improvement Strategies in Sub-Saharan Africa

In 2014, Liu *et al.* (2014) developed and piloted an inexpensive and more portable CT imaging solution. Their analysis found this solution to be feasible and while the images produced were more susceptible to degradation by movement artifact, the authors suggested computational algorithms could correct this issue, many of which are now common practice (Liu *et al.*, 2014; Ko *et al.*, 2021; Ren *et al.*, 2022). However, the re-configurable model proposed by Liu *et al.*(2014) has not gained widespread adoption and instead, manufacturers continue to push refurbished medical imaging equipment, which are known to have many associated challenges (Global Health, 2023). Some organisations have made efforts to collaborate with manufacturers to develop technical solutions to improve diagnostic imaging services in developing countries, particularly in remote regions, the present research aiming to supplement these efforts with a direct comparative assessment of user need (WHO, 2024b).

In Africa, the Consortium for Advancement of MRI Education and Research (CAMERA) is the leading advocate for enhancing MRI services through high quality training, and are working toward ensuring MRI services can meet the needs of the African population (CAMERA, 2024). This organisation was founded in response to the shortage of MRI services throughout Africa, despite its role in transforming patient outcomes for chronic conditions such as stroke, dementia and heart disease (CAMERA, 2024). The organisation has brought awareness to the ongoing and severe shortage of MRI equipment across Africa and has inspired the present research. CT imaging is also crucial in the diagnosis and management of various acute and chronic diseases, particularly where time sensitive, and enhancing these services could have a profound impact on African healthcare, with particular impact in Sub-Saharan Africa where CT imaging services are least accessible (WHO, 2024).

2.7. Comparing Radiographers' Needs in Developed and Developing Regions

The secondary research highlights several commonalities and disparities between radiographers in Ireland and SSA, whether in their access to resources, educational and training opportunities, or health professional shortages. The following analysis examines the challenges and opportunities unique to radiographers in diverse contexts.

2.7.1. Common Challenges Across Ireland and SSA

Effective medical device design should start with a comprehensive user needs assessment to ensure the manufacturer is familiar with the intended user and the context in which the device will be used (Shaheen et al., 2021). Failure to appropriately address these factors may increase the rate of use-related errors and subsequent device recalls, which could ultimately harm both the user and manufacturer (Fox-Rawlings et al., 2018; Congenius, 2023; Davis, 2024). CT radiographers across Ireland and SSA appear to share the common challenges of staff shortages, occupational stress, increased scan capacity demand, disproportionate distribution of equipment, increasing mental load, and a lack of appreciation and service prioritisation. This indicates a need to target workforce shortages in both regions, enhance training and support for technological advancements, and pursue the equitable distribution of CT services in both regions. The research acknowledges that such requests cannot be resolved with region-specific CT system design, alone. However, identifying these factors can help inform CT system design with an aim to lessen these challenges until greater contributions are made.

2.7.2. Contextual Differences Between Ireland and SSA

Identifying contextual differences is as important as identifying contextual similarities, the combination allowing a comprehensive understanding of the user and the specific context of use to ensure user-specific and region-specific design inputs can be made. One of the largest differences between CT imaging services in Ireland and SSA is access to resources with electrical and internet connectivity supplies often cited as major obstacles in SSA (Kawooya *et al.*, 2022; Anazodo *et al.*, 2022). Challenges with infrastructure in Ireland related to CT typically include insufficient hospital bed capacity and ageing medical imaging equipment, challenges also experienced in SSA (Soyemi and Aborode, 2022; Eolas, 2024). This basic difference suggests the need for more physically-robust CT systems in SSA that can withstand fluctuations in electrical and internet connectivity, as proposed by Dr. Ogbole (2022) regarding MRI service enhancement across Africa. Eolas (2024) have reported almost 50% of the x-ray systems in Ireland are over ten years old, again indicating the need for robustness where health facilities cannot afford to regularly replace their imaging equipment, as is often the case in SSA. This also stresses the need to increase investment in medical imaging services in Ireland and in SSA (Aderinto, 2023; Eolas, 2024). To increase the abundance and availability of medical equipment in developing countries, some have advocated for frugal innovation, as the concept of transferring medical devices designed for the developed world directly to developing regions is not sufficient, and multiple design variants may deliver more sustainable solutions. Frugal innovation describes design that is focused on durability, robustness, cost of prolonged ownership and simplicity of use (Piaggio *et al.*, 2021).

In addition to this, radiographers in SSA are more frequently being expected to interpret radiographic images in the absence of a radiologist, as mentioned (Kawooya, 2012). This may place additional mental strain on radiographers, despite radiographers in Africa showing a generally positive attitude to image interpretation, and comparable accuracy to radiologists (Kawooya, 2012; Aldoihi and Hammami, 2019). Perhaps such role progression could indicate a need to incorporate image interpretation assistance features enabled by artificial intelligence (AI) (Hosny *et al.*, 2018). However, the needs of radiographers must be prioritised to ensure design modifications can deliver a net positive, cause minimal disruption and importantly, improve access to CT imaging services where limited.

The expectation for radiographers to interpret radiographic images in the absence of a radiologist has not been extensively reported in Ireland. Most radiographers in Ireland (65%) have expressed their support for the implementation of AI features in radiology, however, there is a reported resistance in 50% of radiographers toward using AI for final image interpretation (Ryan *et al.*, 2021). Perhaps radiographers would be more amenable to image interpretation assistance tools, with final interpretation by radiologists or even reporting radiographers. Interestingly, radiographers across Africa have shown overwhelming support (86%) for AI-enabled image interpretation of common regional conditions, such as tuberculosis (Botwe *et al.*, 2020). However, the study performed by Botwe *et al.* (2020), asked participants to rate their support of AI assisted image reporting tools by ‘flagging’ conditions rather than for final image review (Botwe *et al.*, 2020; Ryan *et al.*, 2021). This discrepancy considered, there is a strong likelihood that AI-enabled image interpretation assistance is likely to be embraced by radiographers in Ireland and SSA. However, this move should be guided by policymakers and the role of the radiographer in this context should be well defined, a concern raised by those in Ireland and SSA (Botwe *et al.*, 2020; Ryan *et al.*, 2021). Care should be taken as several studies have raised concerns around the inclusivity within novel machine learning algorithms, wherein minority ethnic populations may be excluded from testing (Grant, 2022; Tripathi et al., 2023; Doo and McGinty, 2023).

2.8. Economic and Policy Factors Influencing Access to Computed Tomography

This section explores the economic and policy factors which may influence access to CT imaging services in Ireland and SSA.

2.8.1. Economic Factors Impacting CT

As CT imaging demand continues to rise, imaging system manufacturers are responding with increased scanner capabilities, from AI-enabled image reconstruction to semi-conductor detectors, and ultra-fast scan acquisition times (FHC, 2024; Fornell, 2024; Springer Nature, 2024). Each of these features claims to either increase scanner capacity, improve diagnoses, streamline workflow efficiency, or improve patient outcomes, while many of these features are increasing scanner purchasing price and scanner maintenance requirements, making it increasingly challenging for developing countries to increase their abundance of CT scanners (Harmonay, 2022). One report claims the cost of purchasing a CT scanner doubled between 2021 and 2022 amid supply chain disruptions, the Covid-19 pandemic and increasing demand (Harmonay, 2022).

Some CT system manufacturers offer more cost-effective models to developing countries, however, costs associated with shipping, installation, maintenance, consumables, staffing and insurance must also be considered (Block Imaging, 2024). Many developing countries are therefore reliant on finite equipment donations and government schemes. According to Marks *et al*. (2019), up to 70% of the medical equipment in SSA has been donated, only 10-30% of which is operational. This study argues that where medical devices donations are poorly executed, they can burden healthcare systems, many of which are already operating in challenging environments. Investigating the specific challenges encountered by radiographers in separate contexts could help to inform the design of CT imaging systems to better serve specific populations.

Another challenge facing the under-served populations of SSA is the privatisation of medical imaging services, for example, 23% of the medical imaging equipment in Zambia belongs to the private sector, similar to 30% in Ireland. However, just 4% of the Zambian population have access to private healthcare, compared with 47% in Ireland (Foley *et al.*, 2012b; Mbewe *et al.*, 2020; Pope, 2023). As mentioned, public-private partnerships have been suggested as a means to bridge the gap between public and private services in countries such as South Africa (Kabongo *et al.*, 2015). In addition to this, the ministry of health in Mozambique remains committed to enhancing public CT imaging services and are working toward having a minimum of one CT scanner in each hospital and two CT scanners in central, urban hospitals (Goosen, 2024). In 2023, their initiative successfully procured a new scanner for four hospitals across the country, while ensuring local medical specialists were trained and network infrastructure was secured (Goosen, 2024). The ministry of health in Mozambique has outlined several factors to consider when enhancing CT imaging services in developing regions, including ensuring human resources are trained, warranties are in place, maintenance and after-sales services are secured, and infrastructural readiness and the re-stocking of consumables (Goosen, 2024). Following this structure, the delivery and implementation of CT imaging services in SSA can be enhanced.

2.8.2. Policy and Regulatory Frameworks for CT

As mentioned, some countries in SSA report the under-use of medical imaging equipment due to insufficient training and a lack of standardisation, among several other factors (Aderinto, 2023). Several other studies report this lack of training and standardisation has caused imaging equipment over-use (Mahmoudi *et al.*, 2019; Kada, 2020; Kazemi *et al.*, 2023). One proposed reason for this lack of standardisation is the severe shortage of healthcare professionals in SSA, leaving radiographers little time to train and revise protocols (Hr and Mscmed, 2011). In the last decade, clinical imaging referral guidelines have been updated across the African continent and national dose trends are now being monitored in 33 African countries (Kawooya *et al.*, 2022). Radiation safety awareness has improved as a result, much of these improvements attributed to the Bonn Call for Action, an initiative co-founded by the WHO and International Atomic Energy Agency (IAEA).

In Ireland, regular national clinical audits are performed by the National Office of Clinical Audit on quality and safety (Delgado Bolton *et al.*, 2023). This aims to ensure continued monitoring of radiation practices, outcomes, and the provision of feedback to drive timely improvements (Delgado Bolton *et al.*, 2023). As mentioned, there are also regulated CPD programs across Ireland to ensure radiographers keep up to date with modern teachings (CORU, 2024). Harmonising radiation practices between countries is crucial to enhance patient outcomes and safeguard patients and radiographers against error.

2.9. Strategies to Enhance Access to Computed Tomography in Diverse Contexts

This section proposes strategies for enhancing access to CT services in Ireland and across SSA, presenting two distinct models that address the theoretical needs of radiographers in both regions, based upon the secondary research.

2.9.1. First Theoretical Model for Enhancing Access to CT

Dr. Godwin Ogbole (2022) presents an analogy that explains the need for regional MRI system design to enhance access to MRI services across the African continent. In this analogy, Dr. Ogbole compares MRI systems to car manufacturers, claiming the smaller, simpler and less expensive type could render increased MRI system abundance when compared with the luxurious, modern and more expensive system. This theory suggests modern imaging technologies and their benefits are limited to high-income countries who can afford such luxuries. Dr. Ogbole advocates for a retrograde movement toward the less-advanced imaging technologies, their relative affordability enabling increased abundance in developing countries (Ogbole, 2022).

The first theoretical model embraces frugal innovation to increase the abundance of CT scanners to help resolve many of the challenges discussed in this chapter, for example, reducing the complexity of equipment to reduce the complexity of maintenance and servicing (Ogbole, 2022; Anazodo *et al.*, 2022). This could help to reduce the rate of morbidity and mortality from the failure to receive timely medical imaging, the premise being that having a CT scanner and being able to perform CT scans, regardless of the reduced capability, is preferable to having no scanner at all (Driban *et al.*, 2023). However, the shortage of healthcare professionals and the lack of educational standardisation and CPD endorsement remain to be resolved.

2.9.2. Second Theoretical Model for Enhancing Access to CT

The second proposed model for enhancing access to CT imaging services is heavily influenced by radiographers' perspectives and opinions. This model would incorporate more high-tech and advanced features, for example, remote operation and artificial intelligence. This model strives to enhance the experience of the radiographer through assisted operation, for example through remote expert opinion or AI-enabled assistance, where shortages of radiographers and radiologists persist. Some manufacturers have already added remote access technologies for CT systems which have enabled radiographers and/or radiologists to remote into CT system control rooms to troubleshoot issues (Fornell, 2024). Although reportedly less frequently utilised, this would also permit radiographers at an alternate location to initiate CT scans to help overcome radiographer shortages. However, radiographer shortages are effectual around the globe, and this in isolation cannot resolve these issues (Konstantinidis, 2023; Fornell, 2024). However, this feature could enable the more experienced radiographers to provide critical support to less experienced radiographers by answering their questions, and selecting protocols and exposure parameters (Fornell, 2024). Ultimately, this could help to avoid unnecessary or inappropriate radiation exposures, improving quality of care and reducing scanner downtimes where radiographers are not confident enough to use CT scanning equipment (Aderinto, 2023; Fornell, 2024).

While the first proposed model may suit those in developing and rural areas, the second proposed model may suit those in both developed and developing countries. This model focuses on enhancing and expediting diagnoses using advanced scanner features and capabilities. Incorporating machine learning or smart features into CT systems could help to reduce some occupational stresses from repetitive action, and could help resolve some uncertainties (Fornell, 2024). The exact features with which the second theoretical model should be equipped should be discerned from the primary research associated with the present research. However, some notable features that are already in practice include the 3D camera for body contour detection and analysis to assist patient positioning (Booij *et al.*, 2021; Salimi *et al.*, 2023). This has the potential to reduce both the physical and mental demands on radiographers, while streamlining workflow efficiency and producing more consistent results (Salimi *et al.*, 2023; Imaging, 2023). Smart protocoling is another novel feature that could enhance workflow efficiency through automated protocol adjustment, regardless of the radiographer's experience level (Fornell, 2024). This could help less experienced radiographers avoid unnecessary radiation exposures and achieve better patient outcomes (Fornell, 2024).

Another innovation worth noting is the ultra-fast scan acquisition, a feature with great potential in improving outcomes in time sensitive scenarios such as trauma and stroke (FHC, 2024). This also reduces the impact of patient motion on image quality and can improve patient throughput which could potentially help reduce CT scan waiting lists and help patients to achieve quicker diagnoses. However, any CT system enhancement should not increase workload on the already strained radiographers as burnout remains common (Singh *et al.*, 2017; Foley *et al.*, 2020; Sipos *et al.*, 2024).

2.9.3. Comparison of Theoretical Models for Enhancing Access to CT

Both of these models could offer several benefits to radiographers in Ireland and in SSA, the model of choice dependent on their unique needs and priorities. The first model offers a more cost-effective solution and may thus be more desirable where a significant improvement in CT scanner abundance is required, as is often the case in developing regions (Nigatu *et al.*, 2023). The first model sacrifices the more advanced features in favour of abundance, and its implementation would need to be met with initiatives to improve radiographer training and retention to counter radiographer shortages. As a more basic model, less frequent and less complex maintenance is expected, as well as a less complex training burden. The most significant potential disadvantage with the first model is the potential inferior diagnostic quality when compared with the second more advanced model. However, the increased access facilitated by the increased scanner abundance this model could enable would likely offset this as a greater number of patients would be able to receive potentially life-saving imaging. Increasing the abundance of CT scanners and access to CT scans also raises concerns around the appropriateness of radiation exposures and would need to be met with improved radiation safety awareness.

Conversely, the second proposed model would likely enhance diagnostic accuracy, but would come with increased purchasing price when compared with the first model (Hartman, 2023). The second model may be more appropriate for those whose priorities align with remote operation, international collaboration, and advanced imaging capabilities. For example, radiographers in SSA are increasingly expected to deliver scan results in the absence of a radiologist and may thus be interested in AI enabled image assistance or remote expert opinion. However, their choice of model would depend on the specific priorities of radiographers in a specific country or region. For example, they may prioritise increased scan capacity and reduced spend over image interpretation assistance and may therefore opt for the first proposed model. To ensure that CT systems can effectively serve developed and developing regions, manufacturers must consider the unique needs of radiographers in each region, and the specific context in which the CT system will be used.

2.10. Summary and Gaps in Research

Aldoihi and Hammami (2019) merit the success of the CT scan on how well the radiographer can operate the CT system. However, research on radiography appears to concentrate on the patient experience and often neglects to address the needs of the other primary user, the radiographer (Mbonambi and Kekana, 2023). This means manufacturers must gather information on user need direct from the user before ensuring their needs are met in device design (Nichols, 2024). User need analyses are required before any medical device can be approved, however, these remain open to the manufacturer's interpretation and many believe them to be burdensome (Shin and Lee, 2023). Several cases of user exclusion have subsequently been reported in these analysis, and where diverse needs are ill considered, operational challenges can occur. With consideration for much of the medical imaging equipment in developing countries coming from developed countries, patients in the former may be inherently vulnerable to usability challenges which can have a direct impact on service availability (Tsai *et al.*, 2023).

The importance of including the user in the design of CT imaging systems should not be underestimated, their application in almost every aspect of healthcare. Nonetheless, radiographers are commonly considered one of the most neglected healthcare professions in healthcare research (Lamsal, 2015). This leaves radiographers as a whole particularly vulnerable to usability challenges when compared to the more extensively researched healthcare professions such as doctors and nurses. As mentioned, radiography tasks are diverse and highlight the need for thorough user needs analyses both to mitigate risk and enhance workflows. As mentioned, this is particularly important considering radiographers often deliver relatively large radiation doses through CT (Muhogora *et al.*, 2010; Kazemi *et al.*, 2023).

The present research aims to contribute to the limited discourse on radiographers' occupational needs and preferences, with particular emphasis on demographic and contextual variations and their impact on usability and access to CT. Through comparative assessment, the research aims to identify disparities between CT radiographers in developed and developing regions to determine whether region-specific design variations are indicated. The research recognises the nuances in tacking such obstacles and aims to highlight these issues to encourage CT system manufacturers to listen and respond to the needs of radiographers in diverse contexts, with the ultimate aim to achieve equitable imaging healthcare (Shaheen *et al.*, 2021). The damaging effects that reduced access to CT imaging continues to have on developing country populations cannot be ignored, and perhaps solutions driven by the primary end user may assist in achieving equitable healthcare.

Chapter 3: Methodology

This chapter outlines the research design and method rationale, and addresses the ethical considerations taken throughout the study. This chapter also briefly addresses the data collection and analysis methods used.

3.1. Conceptual framework

The conceptual framework describes the background of the research design, as well as the relationships that exist between the key concepts and variables of the research (Singh, 2023). This research examined the user experiences of CT radiographers in Ireland and SSA to determine whether variations in demographic and contextual factors would impact their user experience (Figure 7). This enabled several recommendations to be developed for improved access to CT imaging services in Ireland and in SSA.

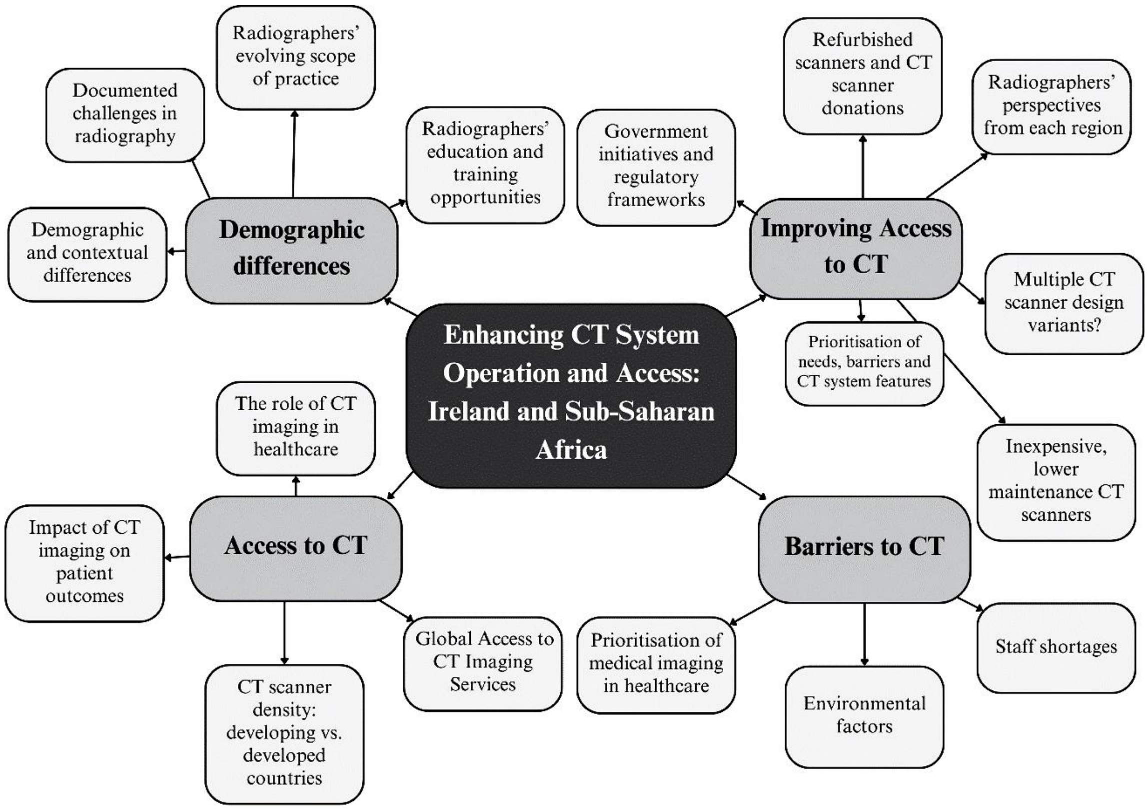

Figure 7: Conceptual Framework (Author's Own)

3.2. Research Design

The research design is presented through means of the research onion, as conceptualised by Saunders *et al.* (2019). This tool summarises the core features of the present research, from the research philosophy to the approach to theory development, to the research strategy, the methodological choice, the time horizon, and finally, the techniques and procedures used (Figure 8).

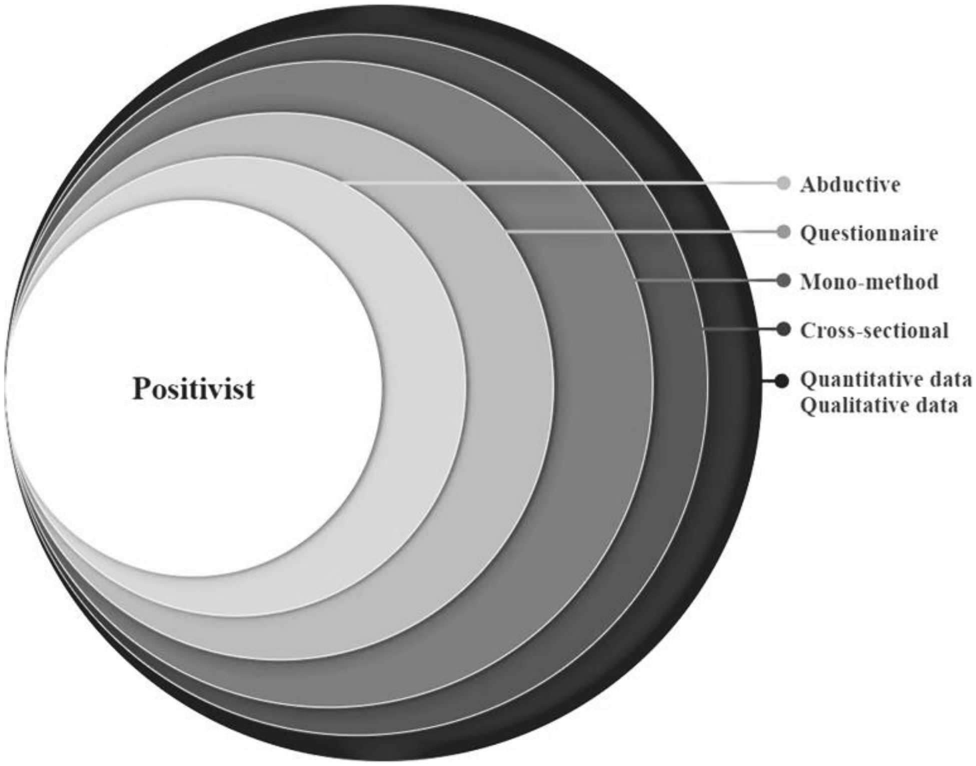

Figure 8: Research Onion for The Present Research (Author's own)

3.2.1. Research Philosophy

The research philosophy describes the collection of viewpoints or practices that comprise the key concepts and variables associated with the research tools used in its methodology (Dissanayake, 2023). For example, this study used positivism to gather objective material from a large sample size (Ryan Blackwell, 2018). This approach assumed the position that facts can be proven and that observations and measurements can deduce what reality is, using phenomenalism, deductivism, inductivism, and objectivity while the research and researcher remain independent of one another (Ryan Blackwell, 2018). This study used logical reasoning to ensure that precision and objectivity underpinned the research and that social reality had no influence on its findings (Creswell, 1994).

While the research was interested in analysing diverse demographic and socio-economic contexts, and varied social realities, these factors were analysed through quantitative and pragmatic means. The research used positivism to explore the varying perspectives of CT radiographers in Ireland and in SSA, while maintaining the epistemological position that the complexity of social situations can be explained through fact (Askarzai and Unhelkar, 2017). Data were gathered through a semi-structured online questionnaire, its analysis focused on deriving quantitative data through closed questions. However, the combination of closed and optional open questions meant there were elements of interpretivism, while the research remained primarily positivist, and was aimed at generalising its findings to a larger population (Askarzai and Unhelkar, 2017).

3.2.2. Research Approach

This study adopted an abductive approach within a positivist framework, neither inductive nor deductive analyses were sufficient in isolation (Askarzai and Unhelkar, 2017). The closed question analysis used deduction to validate or invalidate pre-conceived concepts, while the open question analysis used induction to allow patterns and themes to emerge from the data (Saunders *et al.*, 2019). This combination allowed the researcher to develop hypotheses to explain the observed phenomena. This also allowed data to be generalised to a larger population, a commonly reported disadvantage when using inductive analyses alone (Askarzai and Unhelkar, 2017). Thus, the online questionnaire combined structured and unstructured data collection methods.

3.2.3. Research Strategy

A semi-structured online questionnaire was distributed to CT radiographers across Ireland and SSA. Online questionnaires were deemed most suitable for the present research study on account of their relatively higher and quicker response rate when compared with other data collection methods such as interviews (Menon and Muraleedharan, 2020). This was advantageous to the present research with consideration for the time constraints. Online questionnaires are also inexpensive and encourage anonymity which is proven to enhance the legitimacy of responses received (Ong and Weiss, 2000). While interviews are generally associated with greater depth of response, this is heavily reliant on recruiting participants who are both invested and easily accessible which was deemed somewhat impractical for this international research (Codó, 2009). The primary disadvantage of using online questionnaires is the potential exclusion of participants who are lacking computer skills; however, this was unlikely to be an issue considering the highly technical nature of the radiography profession (Nayak and K A, 2019; Barbosa *et al.*, 2022).

3.2.4. Research Methodology

The present researched used a single data collection method to gather quantitative and qualitative data and is therefore considered to be mono-method (Askarzai and Unhelkar, 2017). When compared with traditional mono-method analyses, the combination of quantitative and qualitative data provided a more complete and less-biased picture of the collected data (Askarzai and Unhelkar, 2017). Taking an abductive approach also helped balance the advantages and disadvantages of inductive and deductive methods, if used in isolation. The main disadvantage with combining these methods was the increased time burden, and the requirement to thoroughly understand both. This was overcome by detailed data reasoning in the results section (Askarzai and Unhelkar, 2017).

3.2.5. Research Timeframe

This research was cross-sectional, data collection taking place over eight weeks with no follow-up research planned. Time constraints associated with the present research helped inform the decision to use online questionnaires on account of their relative low maintenance (Menon and Muraleedharan, 2020).

3.3. Research Techniques

The semi-structured online questionnaire was created using Microsoft Forms, an easily accessible and user-friendly research tool commonly used in scientific studies (Rooted Software, 2024). This allowed the questionnaire to be easily distributed using a hyperlink or QR code, the latter convenient for poster printing and display, as in Figure 9. The questionnaire was sent to CT radiographers and radiology departments in Ireland and in SSA. Ireland was chosen as a representative developed country due to its reported 20.3 CT scanners per million inhabitants, falling within the approximate average of CT scanner density across European Union (EU) member states, the majority of which are considered developed (Hermansen, 2017). The countries of SSA presented a stark contrast to these developed countries, with just 14% of countries in the region reported to have one CT scanner per one million inhabitants (Nigatu *et al.*, 2023). Several methods were employed to recruit participants in SSA, considering the challenges of international recruitment.

3.3.1. Questionnaire Design

The questionnaire contained 30 or 31 questions, with participants in SSA answering an additional question on the specific country in which they worked. As mentioned, the questionnaire contained open and closed questions which covered attitude, behavioural, classification, and pre-coding questions, and one routing question asking in which region the radiographer practised i.e., Ireland or SSA. The questions were split across four sections, namely: demographics, context of use, user experience, and critical needs and priorities. All open questions were optional to enhance the participant experience and to elicit only the most valuable information (Ahmad, 2012). Qualitative information gathered through open question responses was used to support the statistical information gathered through closed questions. These closed questions analysed demographic factors including experience level, educational background and training experience, also examining ease of CT system operation and prioritisation of need regarding scanner features. Several closed question typologies were used, from simple dichotomy to multiple-choice questions (MCQs), ranking, and Likert style questions. This enabled ease of analysis as well as standardisation between responses in Ireland and SSA (Ahmad, 2012). The MCQs were determinant or checklist depending on their specific purpose. The questionnaire took approximately 18 minutes to complete, with the longest time to completion 23 minutes and the shortest time to completion just under 2 minutes.

3.3.2. Participant Recruitment

Participants were proficient in English and were presently working as CT radiographers either in Ireland or SSA. This was confirmed through several qualifying questions at the onset of the questionnaire, with participants who did not meet these criteria eliminated at this stage. Proficiency in English would help ensure ethical requirements were met and avoid any errors from misinterpretation which may have threatened the integrity of the research. The questionnaire was distributed via various channels including LinkedIn, Facebook, and Microsoft Outlook e-mail. Throughout the eight-week period in which the questionnaire remained open, multiple efforts were made to share the hyperlink and QR code associated with the questionnaire. This code was also printed on a poster which was e-mailed to multiple recipients across Ireland and SSA and displayed at a local hospital (Figure 9). Radiology services managers (RSMs) in Ireland were contacted via their publicly available e-mail addresses, requesting internal distribution of the questionnaire within their respective hospital sites. CT radiographers across SSA were contacted via LinkedIn, Facebook, and e-mail, with LinkedIn rendering a notably greater response.

The questionnaire was e-mailed to over 180 facilities throughout SSA that were offering radiology services, with at least one e-mail recipient per SSA country contacted (where relevant radiology services were identified). However, the uneven distribution of radiology services in SSA meant certain countries may have had no eligible participants whatsoever (Adejoh et al., 2018). Participants were also asked to distribute the online questionnaire to peers in an attempt to achieve snowball sampling, a method commonly used to contact populations in regions lesser known to the researcher (Johnson, 2014). The initial questionnaire response rate was low and a noticeable bias in the number of responses originating in Ireland was recognised. Several follow up attempts were thus made to encourage further responses, particularly across SSA.

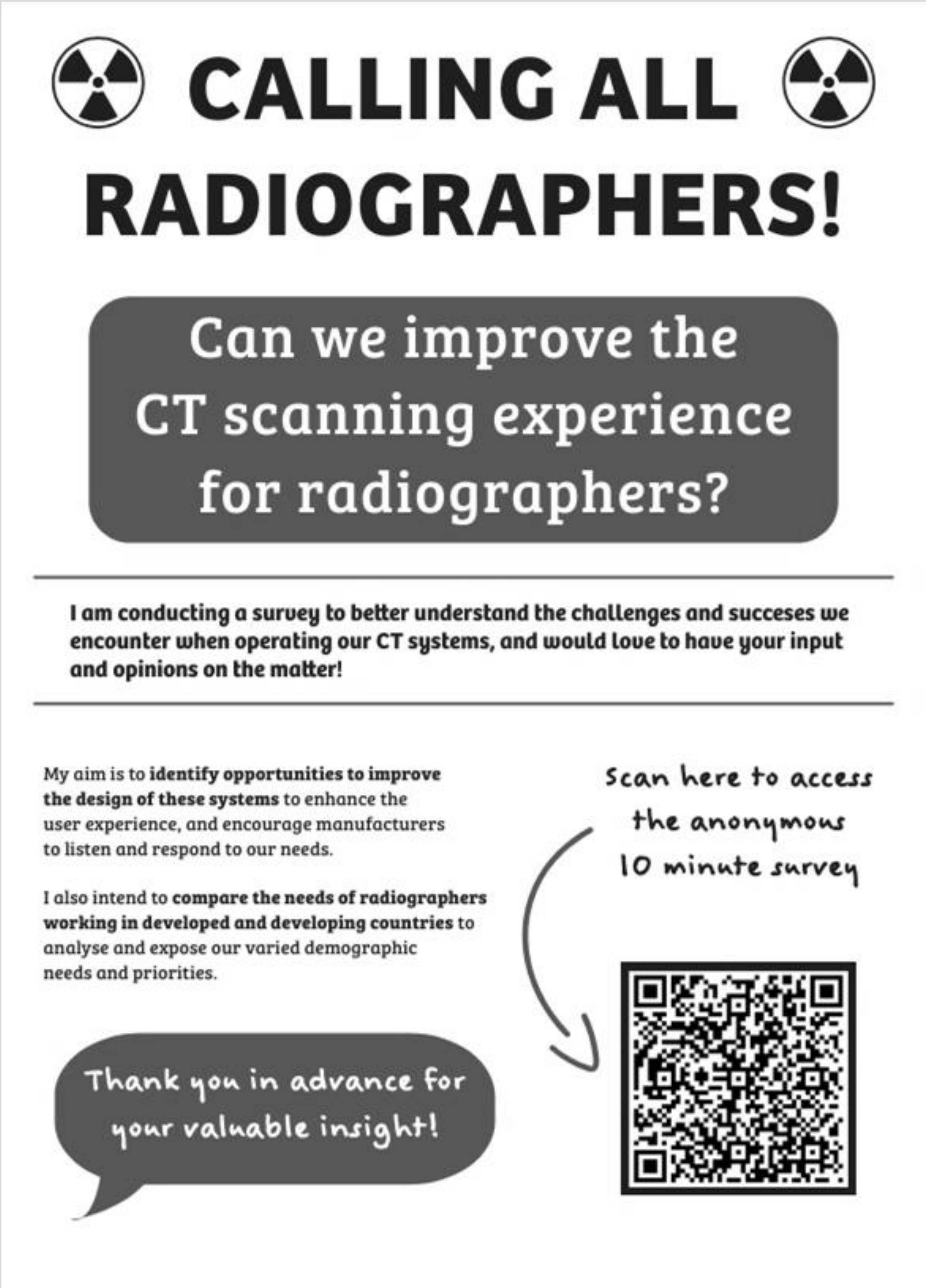

Figure 9: CT Questionnaire Poster (Author's Own)

3.3.3. Sample Size Calculation

The sample size calculation for the present research was particularly challenging as no research was identified to stratify radiographers according to the imaging technology with which they worked e.g., CT, MRI, US, nuclear medicine and so on. Data were available in most countries on the total number of radiographers; however, no data were found on the number of CT radiographers, specifically, in each country. Considering the high demand on CT imaging in recent years, which is expected to rise by at least 100% between 2021 and 2027, one can deduce that the number of CT radiographers may also be increasing (SoR, 2021). A poll was conducted on LinkedIn to assess how many radiographers were trained in CT, the results indicating that 46% of radiographers were trained in CT. The number of poll responses, however, was limited and may have been biased toward radiographers working in Ireland. Nonetheless, the research was forced to rely on estimates without published data on this topic.

In October 2023, there were 3,198 radiographers registered in Ireland, this figure steadily rising due to increased availability of university courses across Ireland in recent years (CORU, 2023; UCC, 2024; TCD, 2024). In Ireland, the ratio of radiographers to total population is therefore approximately 0.000624:1 (Statista, 2023). Assuming that 46% of these radiographers are trained in CT, as per the LinkedIn poll, the ratio of CT trained radiographers to total population is approximately 0.00031, amounting to an estimated 1,471 CT radiographers in Ireland. Limited data in SSA meant there was no information on the total number of radiographers in many SSA countries, making the sample size calculation for SSA even more challenging (Musa *et al.*, 2023).

Table 2 in Appendix A presents population statistics for the countries in SSA from which questionnaire responses were obtained, excluding Lesotho as no data on the total number of radiographers were found. Averaging the estimated ratio of CT trained radiographers to total population in the five countries from which data could be obtained (0.000016), and the cumulative population of the six SSA countries included in this study (358.1mn), we can approximate there are 5,730 CT trained radiographers in these six SSA countries, in total. Combining this figure with the estimated 1,471 CT trained radiographers in Ireland, we get a total required sample size of 148, with a 95% confidence interval and an 8% margin of error (Figure 10) (SurveyMonkey, 2024).

Figure 10: Sample Size Calculation (SurveyMonkey, 2024)

3.4. Ethical Considerations

Several ethical considerations were made to ensure informed consent was obtained and no sensitive data were collected. Each research participant was required to provide voluntary and informed consent before commencing the questionnaire by ticking all four options of a tick-box question. The questionnaire was accompanied by an introductory paragraph explaining the research purpose to ensure that any consent obtained was informed. The questionnaire was consistent and followed a logical flow to avoid any confusion and to increase participant satisfaction. Prior to formal distribution, the questionnaire was piloted to ensure any ambiguities were removed. Ethical exemption was also granted prior to data collection and participant recruitment, and participants were contacted only via publicly available means. All responses were anonymous with any identifiable information was eliminated. No sensitive data were collected.

3.5. Data Analysis Strategy

The data were automatically collected and stored using Microsoft Forms, before being exported to Microsoft Excel and manually cleaned of data entry errors and identifiable information. The data were then organised according to the question typology and closed question quantitative data was analysed using descriptive statistics with various graphs produced. Open question qualitative data were analysed using thematic analysis and various word cloud formations and quotations were produced. This helped identify any themes, patterns, trends and relationships in the data (Nemoto and Beglar, 2014). In line with the abductive analysis approach, meaningful conclusions were drawn through the concurrent analysis of statistical and descriptive data (Askarzai and Unhelkar, 2017; Singh and Jassi, 2023).

Chapter 4: Results and Analysis

This chapter highlights the key barriers to CT imaging in Ireland and in SSA, which are of varying significance. This chapter also examines the specific challenges facing radiographers in each region from user interface interactions to equipment malfunctions, maintenance, and servicing. This chapter also provides insights into different radiographers' educational and training opportunities, as well as into desired features or areas for improvement. Due to the limited sample size accomplished, these findings may not be wholly representative of the populations of Ireland and Sub-Saharan Africa. However, the data indicates important trends and patterns in the user experience of radiographers in both regions and highlights the importance of addressing each of these factors in enhancing user satisfaction and patient outcomes (Familoni and Babatunde, 2024).

4.1. Questionnaire Overview: Responses and Participant Demographics

The online questionnaire was sent to potential participants across Ireland and SSA through various distribution channels. An e-mail invitation was sent to over 180 healthcare facilities across SSA in which radiology services were offered, asking recipients to distribute the questionnaire to their respective radiology departments. In addition, eight medical imaging centres/organisations across SSA were contacted via Facebook, and 56 potential participants were contacted via LinkedIn. Recipients were again asked to distribute the questionnaire to anyone in their network who may be interested in partaking, aiming to achieve snowball sampling (Johnson, 2014). The questionnaire was sent to radiographers in both public and private healthcare facilities of varying sizes to achieve a representative sample.

In Ireland, an e-mail invitation was sent to ten radiology services managers (RSMs) in both public and private healthcare facilities. The questionnaire was also shared within a Facebook group containing 1.8 thousand members, entitled 'Radiographers Ireland'. A further seven radiographers were contacted via LinkedIn and asked to distribute the questionnaire among their peers. The aforementioned poster was printed and displayed in a local hospital, while several former colleagues and classmates of the researcher were invited to participate. Several follow-up attempts were made via e-mail, while repeated posts were shared across LinkedIn, Facebook and Instagram. The questionnaire remained open through an eight-week period, from May 22nd to July 17th, 2024.

4.1.1. Response Rate

52 questionnaire responses were received in total, with 31 from Ireland and 21 from six countries within SSA (Table 1).

Country	*Number of Responses*
Ireland	***31***
South Africa	***9***
Nigeria	***8***
Ghana	***1***
Rwanda	***1***
Lesotho	***1***
Zimbabwe	***1***
Total	***52***

Table 1: Response Distribution

The majority (60%) of respondents were female whilst 37% were male. One respondent identified as 'non-binary', and one chose not to answer. In Ireland, 74% of respondents were female and 23% were male. In SSA, 38% of respondents were female whilst 57% were male. This presents a significant gender distribution difference between Ireland and SSA which may be influenced by local educational and professional dynamics or societal roles and cultural norms (p=0.033, Table 4, Appendix B). For example, approximately 42% of females in SSA do not receive a secondary school education, while in Ireland, 79% of healthcare workers are reportedly female (CSO, 2016; Saavedra and Brixi, 2023).

4.1.2. Geographic Distribution of Participants

Participants were asked to define their geographic working location, 60% working in Ireland and 40% in SSA (Figure 11). In SSA, 43% of respondents worked in South Africa, 38% in Nigeria, and the remaining 19% between Ghana, Lesotho, Rwanda, and Zimbabwe (Figure 11). Unsurprisingly, the majority (65%) of respondents in Ireland worked in urban areas, whilst 19% worked in rural areas and 16% worked in suburban areas. Similar findings came from SSA, with 76% of respondents working in urban areas, 14% in rural areas and 10% in suburban areas. These findings correlate with prior research claiming healthcare facilities are concentrated in urban areas, affirming the idea that many patients have to travel long distances to reach healthcare imaging services as rural areas remain under-served (Nixon *et al.*, 2014; Kiguli-Malwadde *et al.*, 2020). This is likely a result of greater investment in healthcare infrastructure in urban areas, oftentimes due to increased population density in urban areas (Figure 12). While this is true for Ireland, it presents a particularly significant challenge for those in SSA, where an estimated 60% of the population lives in rural areas (Ogunkola *et al.*, 2020).

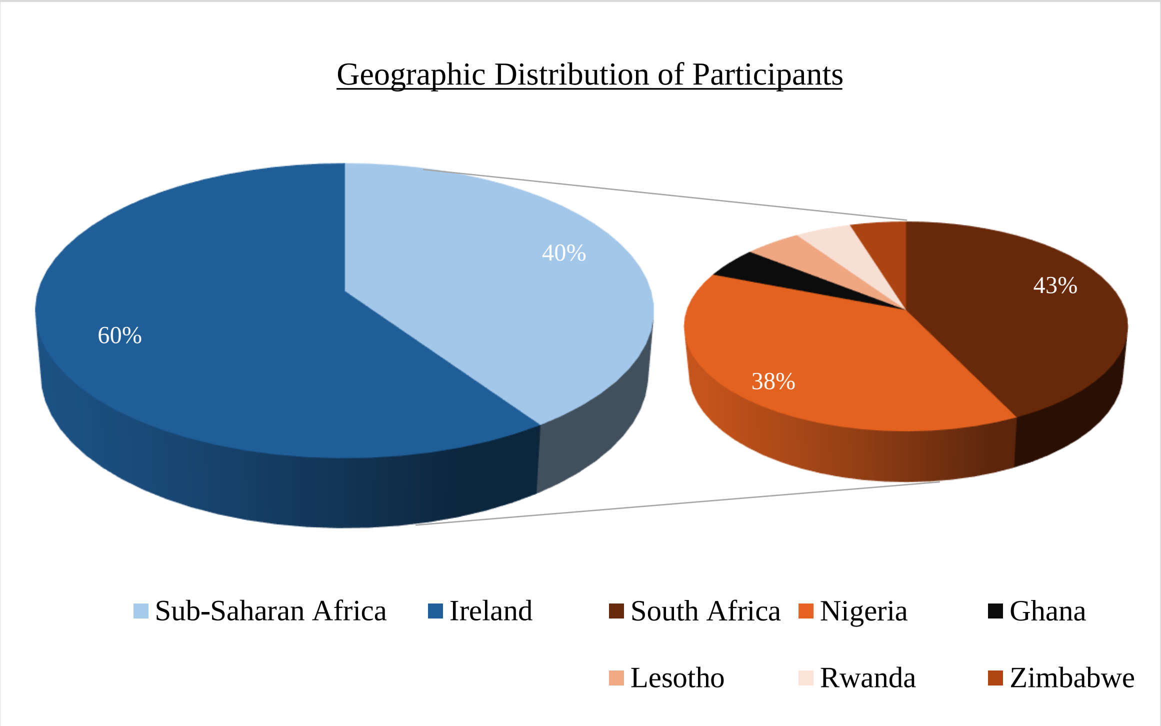

Figure 11: Geographic Distribution of Participants (By Country)

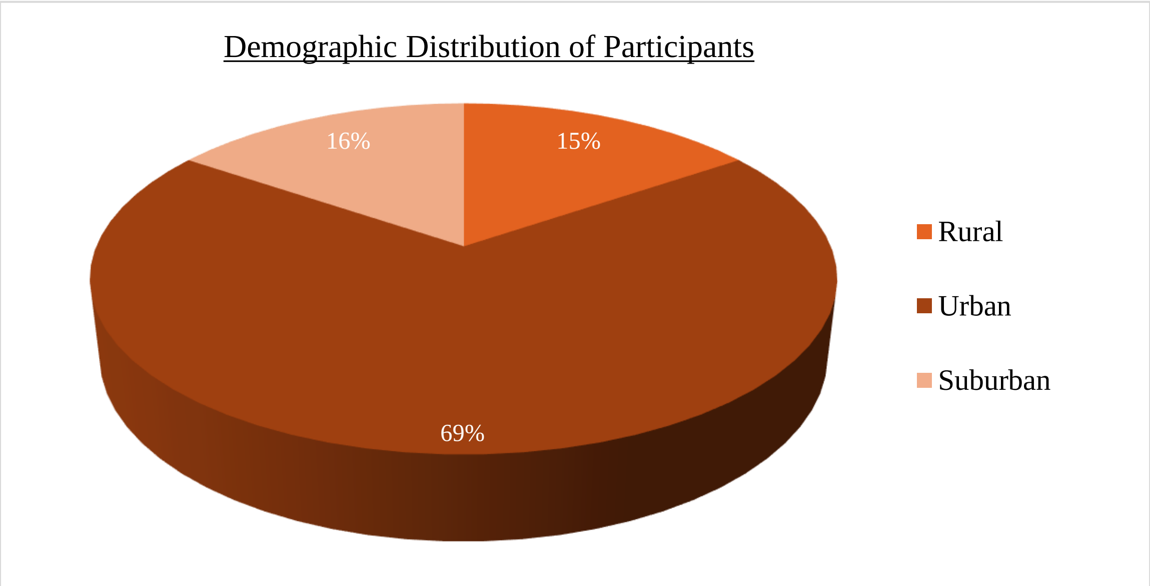

Figure 12: Demographic Distribution of Participants (By Demographic)

64% of overall respondents worked in public hospitals, whilst 23% worked in private hospitals, and 13% worked either in private clinics or outpatient centres. However, considering the disproportionate response from Ireland, the data can be further stratified to show 80% of respondents from Ireland worked in public hospitals, 10% in rural areas, and 10% in suburban areas. Contrastingly, the majority of respondents (59%) in SSA worked either in private hospitals, private clinics, or outpatient centres, with 41% working in public hospitals (Figure 13). This finding correlates with the reported privatisation of healthcare in SSA, much of their medical imaging equipment often belonging to the private sector (Mbewe *et al.*, 2020; Kiguli-Malwadde *et al.*, 2020). This is heavily influenced by government policies, with the public health sector in Ireland supported by the State, and the largest employer in the country (HSE, 2024a). This same support is not seen in SSA, and many healthcare professionals opt to work for private companies in search of better working conditions (Mumbauer *et al.*, 2021).

No participants from either region worked in mobile radiography services. One respondent worked across three separate categories of healthcare facilities (private hospital, private clinic/outpatient centre, and public hospital), whilst three respondents worked in three separate regional categories (urban, suburban, and rural).

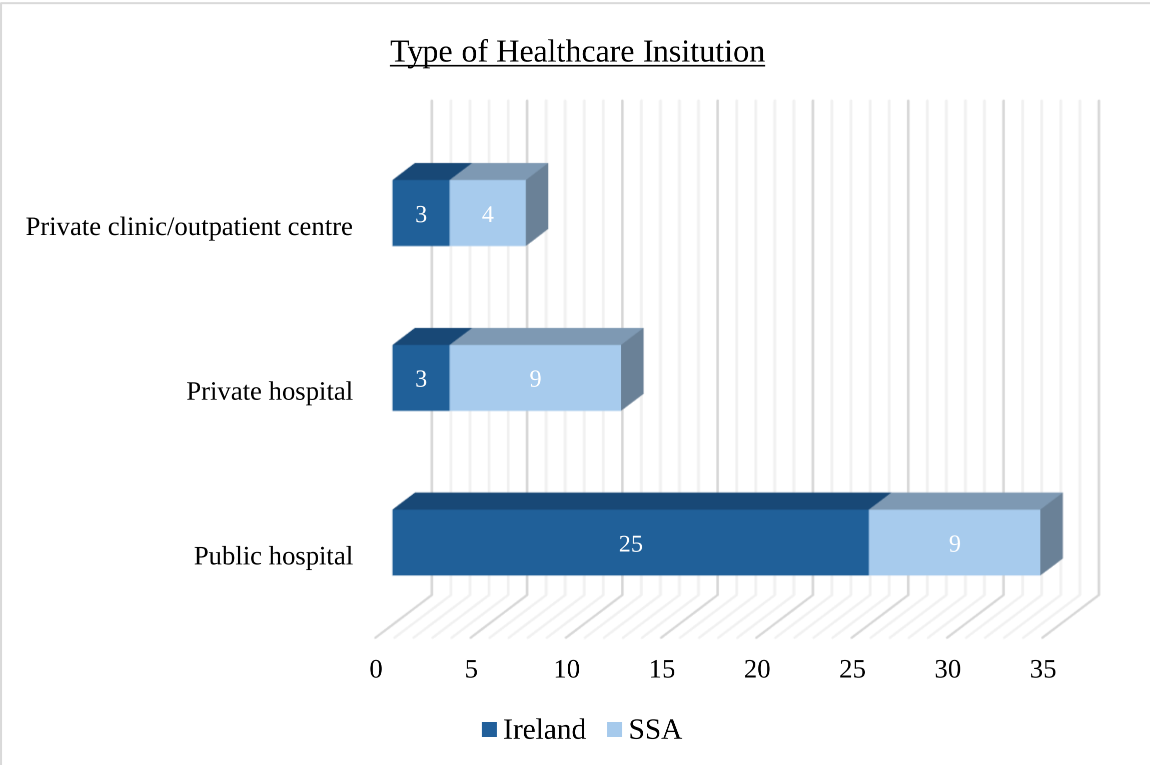

Figure 13: Type of Healthcare Institution in Which Participants Were Working

4.1.3. Education, Training and Experience of Participants

When asked about their educational background, most respondents (80%) had received some level of formal education in CT, 15% receiving a master's degree in CT, 22% receiving a post-graduate diploma in CT, and 5% receiving a post-graduate certificate in

CT. In Ireland, respondents with post-graduate education had either received a post-graduate diploma or master's degree, whilst those in SSA had either received a post-graduate diploma or certificate. In Ireland, 16% of respondents had not received any formal CT education, compared with 29% of respondents in SSA (Figure 14). These findings correlate with the reported under-funding of higher education on the African continent (UNESCO, 2023). Despite this, 38% of respondents in SSA had pursued post-graduate education in CT, compared with 29% of respondents in Ireland. However, one must note these findings may be somewhat inflated, as those with further education in CT may be more inclined to partake in research related to CT imaging and its enhancement.

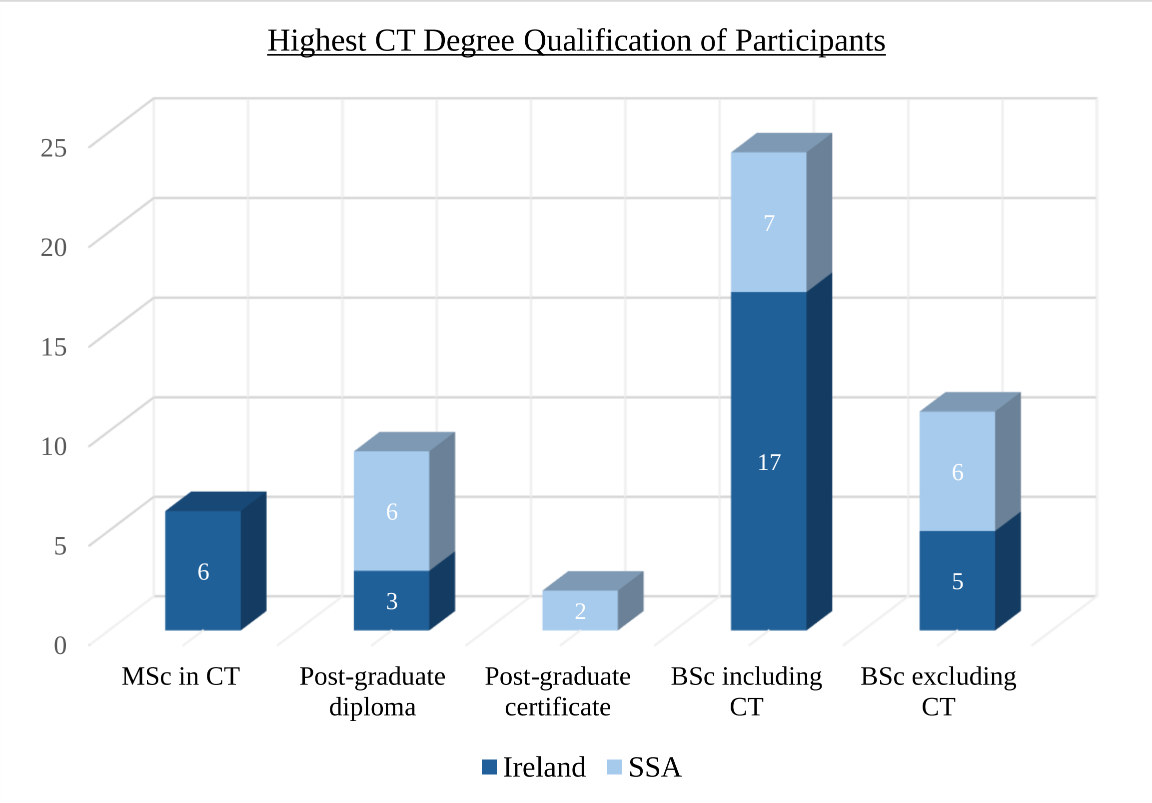

Figure 14: Highest Degree Qualification in CT

Overall, one respondent claimed they had received no CT training outside of their formal education, however, most respondents (84%) received training from colleagues, with 43% undertaking independent online learning, 35% receiving formal classroom training sessions, and 49% receiving direct training from CT system manufacturer(s). These findings highlight the prevalence of informal training from colleagues in the profession, which could indicate a need to increase investment in formal CT training programs to ensure the passage of legitimate knowledge. 43% of respondents had undertaken independent online learning, again indicating the need to formally educate radiographers on CT. The findings also suggest a need to standardise training programs to ensure consistency across regions. In Ireland, 39% of respondents had received training direct from the manufacturer, compared with 62% of respondents in SSA, the increased prevalence of manufacturer training in the latter potentially related to partnership agreements or initiatives in developing regions, such as those provided by Siemens Healthineers AG (2023). Developing regions such as SSA also have limited access to regional expertise in manufacturing and maintenance, perhaps indicating a need to educate healthcare professionals directly on CT scanner failures and solutions (De Maria *et al.*, 2015).

Almost half of respondents (44%) had between one and five years of experience in CT imaging, whilst 23% had between five and ten years. 29% of respondents had more than ten years of experience, and just 4% of respondents had less than one year of experience (Figure 15). This distribution indicates a diverse range of expertise among the sample population, with a significant proportion of both lesser experienced professionals (<5years) and more experienced professionals (>10 years) which should provide fresh perspectives and insights into CT imaging over time.

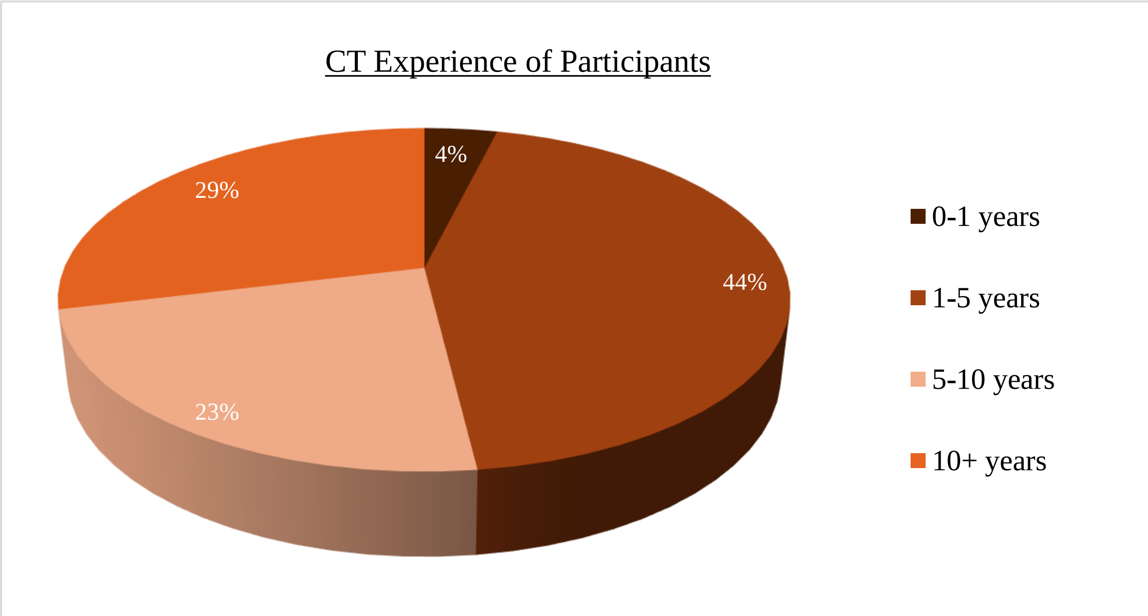

Figure 15: Years of CT Experience of Participants

Overall, respondents were somewhat less experienced in SSA than in Ireland, 57% of respondents in SSA with between one and five years of experience, and 24% with more than ten years of experience. This is compared to Ireland, where 35% of respondents had between one and five years of experience, and 33% had over ten years of experience. One possible explanation for this could be the increasing effect of brain drain on SSA, as experienced radiographers emigrate in search of better working conditions (Ujumadu, 2021). This could also explain the limited proportion of radiographers with mid-level experience (5-10 years) in respondents from both regions (Figure 16).

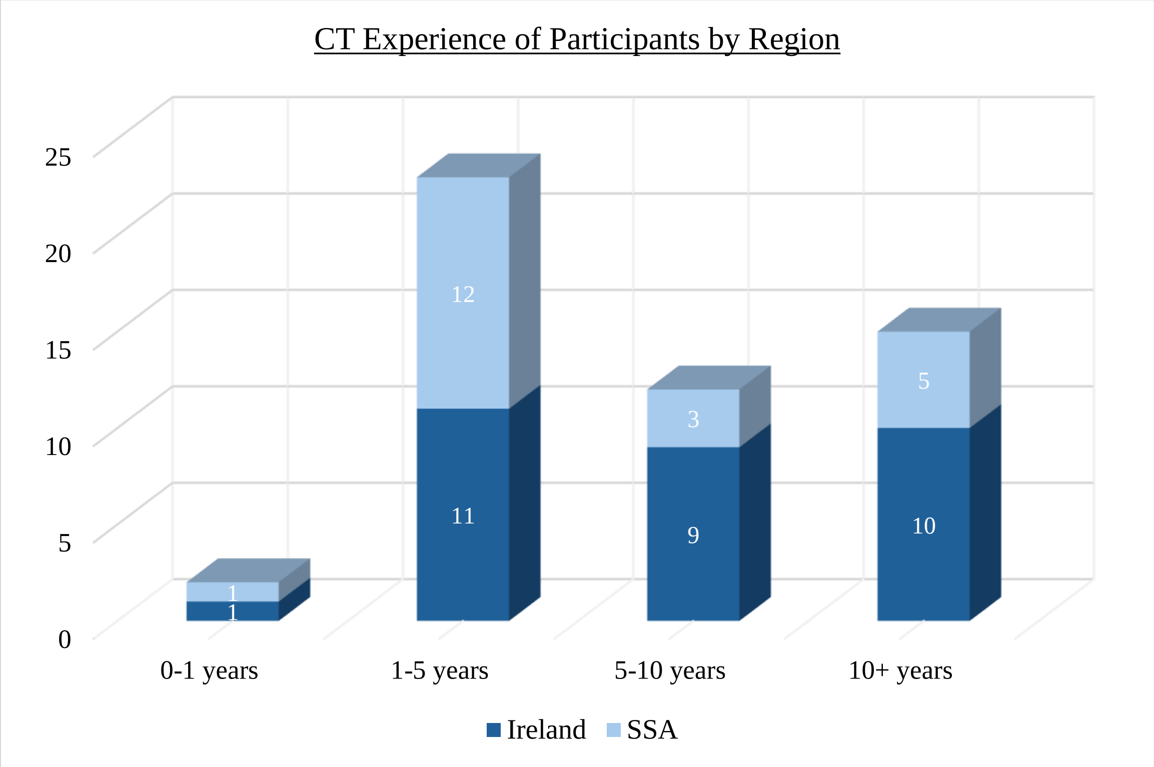

Figure 16: Years of CT Experience of Participants by Region

4.2. CT Scanning Context of Use

Six questions were posed regarding the context in which radiographers managed and operated their CT systems.

4.2.1 CT Scanner Overview: Quantity, Condition and Acquisition Methods

In response to how many CT scanners were available in each facility, 48% of respondents reported having one CT scanner, whilst 31% had two CT scanners, 19% had three CT scanners and <2% had four or more scanners (Figure 17). In Ireland, 32% of respondents had three or more scanners at their facility, compared with <5% of respondents in SSA, indicating a substantial resource disparity between the two regions. This depicts the previously mentioned 'diagnostic divide' and suggests that patients in SSA vulnerable to receiving poorer quality healthcare than those in Ireland. This is because facilities with greater numbers of CT scanners may be better able to handle higher patient volumes, decrease waiting times, and may be more accessible in an emergency which can have several benefits including enhanced and expedited diagnoses and treatment, and the avoidance of unnecessary surgical interventions (Power *et al.*, 2016; Khan and Khan, 2023).

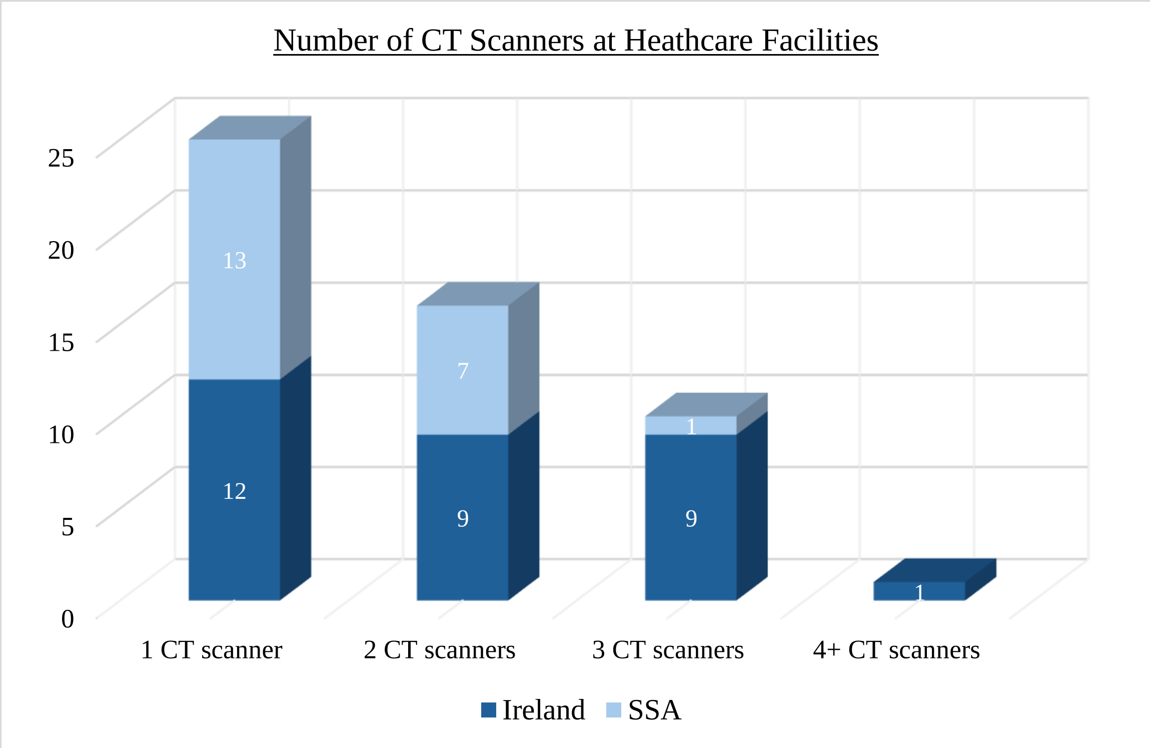

Figure 17: Number of CT Scanners at Healthcare Facilities in Which Participants Worked

Decreased scanner availability in SSA, when compared to Ireland, could suggest the urbanisation of medical imaging services is worse for those living in rural areas within SSA, compared with those living in rural areas in Ireland. Reasons for this decreased scanner availability in SSA are likely financial and infrastructural, though could also be related to the reduced availability of service engineers or their relatively low priority compared to urban facilities. For example, financial resources may be being allocated to services deemed more important than CT, such as emergency services and disease management. However, the research argues the important role medical imaging plays in diagnosing and managing acute, subacute and chronic conditions, and that investment in these services is central to enhancing healthcare (Khan and Khan, 2023).

The majority of scanners (67%) at respondents' healthcare facilities were purchased or leased direct from the system manufacturer, indicating increased reliability and steady manufacturer relationships post-purchase. 13% of respondents indicated their scanners were acquired from a government organisation, whilst 12% indicated theirs were purchased or leased through a third-party distributor. 6% of respondents indicated their scanners were purchased or leased on the second-hand market, with <2% indicating theirs were acquired through a charity organisation, and 10% of respondents uncertain of how their CT systems were acquired. Several respondents selected multiple options for this question, indicating their scanners had been acquired through varied means. 14% of respondents in SSA indicated their scanners were acquired on the second-hand market, whilst no respondents in Ireland selected this option. This may suggest those in SSA are more reliant on affordable, and oftentimes older technologies. However, second hand scanners are often associated with increased breakdowns and therefore, may compound the aforementioned maintenance challenges (De Maria *et al.*, 2015; Global Health, 2023). Most respondents (90%) indicated their facilities had acquired their scanners in a brand-new condition, and just 12% indicated theirs were acquired second-hand/refurbished. 4% of respondents were unsure of the condition in which their scanners were obtained.

Participants were asked to indicate the CT system manufacturers they had used. 63% of respondents had used scanners manufactured by Siemens Healthineers AG, 52% by GE Healthcare Technologies Inc., 46% by Philips Healthcare, 33% by Canon Medical Systems Corp., and one respondent from each region commented ‘Toshiba’ in the text field (Figure 18). Toshiba became rebranded as ‘Canon Medical Systems Corp.’ in 2018, which could indicate these scanners were acquired prior to that date (Canon Inc., 2018).

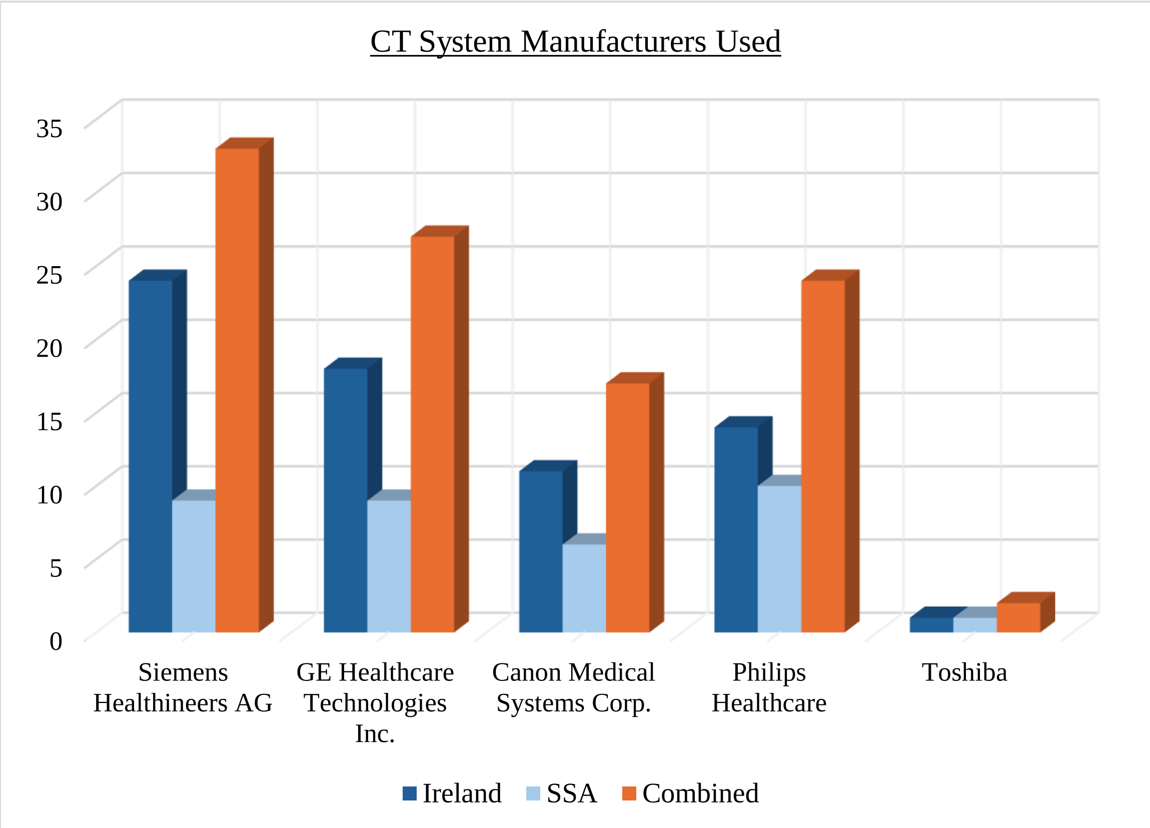

Figure 18: CT System Manufacturers Used by Participants

The large proportion of respondents that had used scanners manufactured by Siemens Healthineers AG may indicate a dominance in the CT scanner market or could be indicative of a preference for this manufacturer among CT radiographers. GE Healthcare Technologies Inc. and Philips Healthcare were also dominant among respondents, both of which are competitive in the market. No respondents commented on any other manufacturer aside from Toshiba, indicating the provided choices were sufficient for both regions.

4.2.2. Closed Question Analysis of CT Access Barriers

Participants were also asked to rank the most significant barriers to CT imaging in their respective countries, as they perceive them. 35% of overall respondents (n=18) selected long waiting lists for CT scans as their most significant CT access barrier (Figure 19). 17 of these responses, however, came from respondents in Ireland with just one respondent from SSA regarding this as the most significant CT access barrier in their country (South Africa) (Figure 20, Figure 21). Over half of the respondents in Ireland (55%) deemed this their most significant CT access barrier, with a further 19% deeming this the second- or third- most significant access barrier. This suggests a strong sentiment among radiographers that long waiting lists for CT scans are the greatest challenge to accessing CT services in Ireland. Conversely, just one respondent in SSA nominated long waiting lists as the most significant CT access barrier, with 10% of respondents in the region ranking this the least significant. The majority of respondents in SSA (67%) deemed long waiting lists for CT scans the fourth, fifth, sixth, or seventh-most significant CT access barrier in their respective countries, with 33% of respondents believing high CT scanner purchasing price for healthcare facilities was the most significant barrier, compared to 10% of respondents in Ireland.

In Ireland, a further 26% of respondents deemed high CT scanner purchasing price for healthcare facilities the second-most significant CT access barrier, and a further 14% of respondents in SSA. This indicates that purchasing price is a significant consideration in both regions, though it appears to be of relatively greater importance in SSA, with respondents in the region also concerned about the high cost of CT scans to patients. In SSA, 67% of respondents ranked this in the top three most significant CT access barriers in their respective countries, compared with 35% of respondents in Ireland. This suggests both populations are concerned with the cost to patients, however, the higher relative ranking in SSA could relate to the privatisation of healthcare in the region and associated affordability and accessibility challenges. No respondents in SSA ranked cost to patients the least significant barrier to CT imaging in their country, compared to two respondents in Ireland. This suggests that while cost to patients is a concern in Ireland, it is not as considerable as it is in SSA, likely reflecting the financial disparities between developed and developing regions, and the impact that financial challenges can have on access to appropriate healthcare.

As a result of such disparities, perhaps radiographers in SSA do not perceive long waiting lists as a significant challenge, due to a preoccupation with more pressing factors such as financial and infrastructural challenges. The variety in response to this question, between Ireland and SSA, could point toward the varied healthcare challenges faced in each region and their resultant prioritisation of need. The large proportion of respondents in Ireland ranking long waiting lists their most significant CT access barrier indicates a strain on the Irish healthcare system and suggests a need to increase CT resources and scanner availability in the country. However, this would need to be met with efforts to resolve radiographer shortages in Ireland, the second-most commonly selected number one access barrier (29%) in the country being the shortage of trained professionals, with a further 23% selecting this as their second most significant CT access barrier. 14% of respondents in SSA selected this as their most significant barrier, with an additional 14% selecting this as their least significant CT access barrier. These mixed perspectives are likely due to regional differences due to the wide geographical area covered in this study, though they could also be due to the varying impacts of brain drain on individual healthcare facilities.

Limited training opportunities for radiographers were also ranked highly in Ireland, 19% selecting this as their second most significant CT access barrier, a further 23% selecting this as their third most significant barrier. Conversely, this issue appeared relatively insignificant to those in SSA, again potentially alluding to a preoccupation with greater issues such as financial and infrastructural challenges. As such, infrastructural challenges such as unstable electrical or internet supply were ranked most significant in SSA by 14% of respondents, a further 33% ranking this second, third, or fourth-most significant. In contrast, 81% of respondents in Ireland ranked this their eighth, ninth, or tenth-most significant CT access barrier. This large disparity aligns with the secondary research in which several links between infrastructural challenges and healthcare problems were evident in SSA (Kawooya, 2012; Botwe *et al.*, 2020; Frija *et al.*, 2021). Neither radiographers in Ireland nor in SSA were concerned with community perceptions of healthcare, 72% of respondents ranking this seventh, eighth, ninth, or tenth-most significant. Regulatory challenges also appeared somewhat insignificant, 63% of respondents ranking this their seventh, eighth, ninth, or tenth-most significant CT access barrier.

Finally, radiographers in SSA were more concerned with insufficient maintenance and technical support when compared with radiographers in Ireland, as expected. 19% of respondents in SSA ranked this their most significant CT access barrier, a further 29% ranking this second or third-most significant. In Ireland, this appeared to be a relatively low-priority issue, as no respondents ranked this their most significant CT access barrier, and more than half of respondents (52%) ranked this seventh, eighth, ninth, or tenth- most significant. This again correlated with the secondary research in which significant service engineer and biomedical professional shortages were apparent throughout SSA (De Maria *et al.*, 2015; Mishra, 2023). This lack of trained professionals may indicate their scanners are not receiving the preventative maintenance services that are customary and even regulated in Ireland, leaving them vulnerable to more frequent machine breakdowns, prolonged downtimes and reduced imaging access, which could suggest the need for enhanced equipment robustness in SSA, the relative disregard in Ireland suggesting superior access to regular maintenance and reliable technical support from engineers and manufacturers.

Overall, these findings suggest a more operationally stable CT imaging environment in Ireland than in SSA, with most respondents concerned on workforce and training related issues, with some regard for the high purchasing price of CT scanners for healthcare facilities. In SSA, the high costs associated with purchasing CT scanners and accessing scans appeared most concerning, with moderate concern for infrastructural and technical challenges. Neither region was majorly concerned with healthcare perceptions in the community or regulatory issues when compared with the other potential barriers in their respective countries. Geographical obstacles were of relatively higher concern in SSA than in Ireland, as was expected with the reportedly large distance between healthcare facilities in the former (Falchetta *et al.*, 2020).

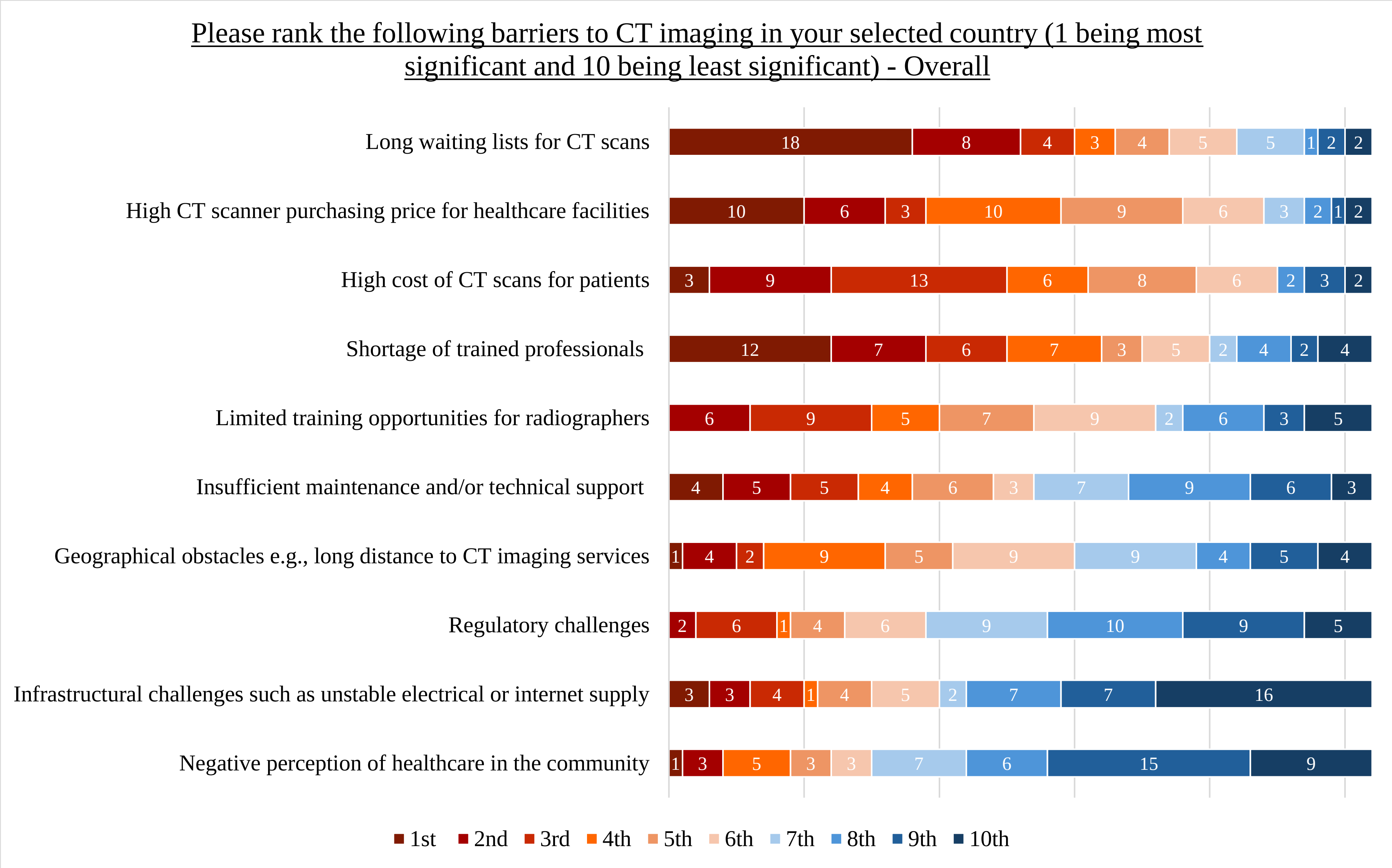

Figure 19: Ranking the Most Significant Barriers to CT Imaging (Overall)

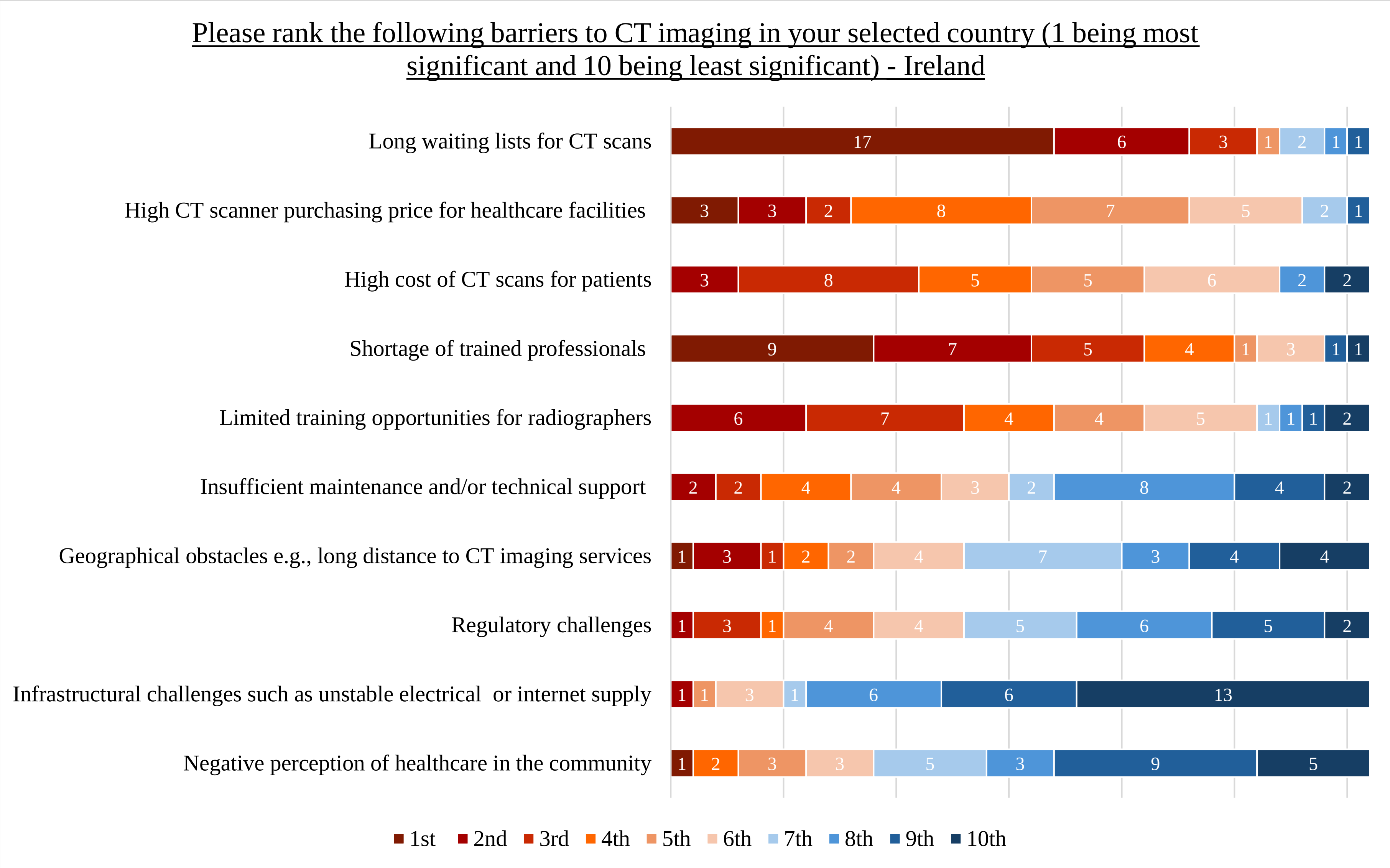

Figure 20: Ranking the Most Significant Barriers to CT Imaging (Ireland)

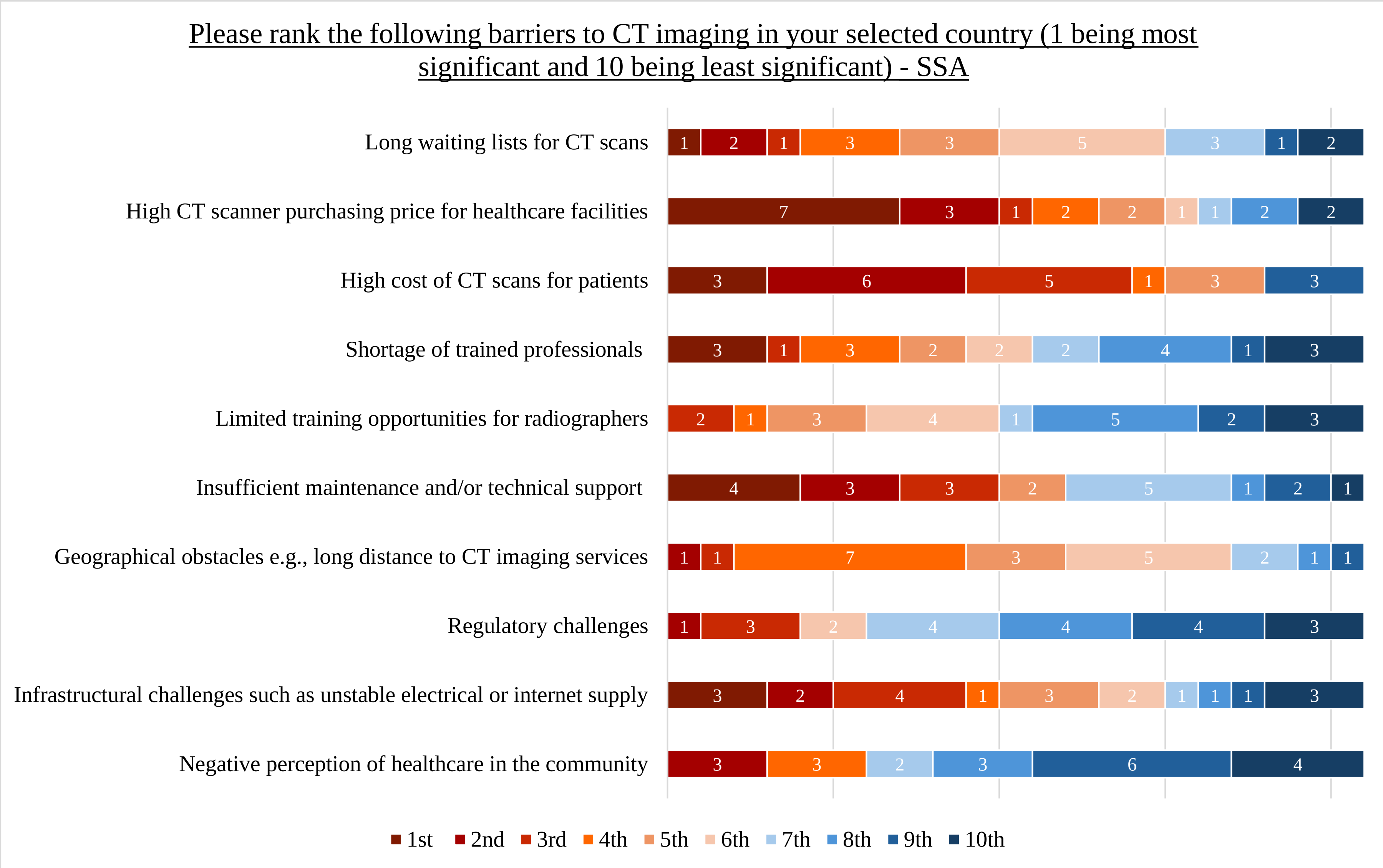

Figure 21: Ranking the Most Significant Barriers to CT Imaging (SSA)

4.2.3. Open Question Analysis of CT Access Barriers

As seen in Figure 22, when invited to elaborate on a specific challenge their department had faced regarding the listed barriers, 50% of respondents in Ireland mentioned *'staff shortages'*, compounded by *'lengthy waiting lists'* and *'increasing demand'*, in line with the above deduction. One respondent mentioned the government-imposed hiring embargo on healthcare workers in Ireland in 2024 as responsible for machine downtime, and two respondents reported CT scanner under-use as a result of staff shortages. One respondent believed increasing their patient lists could be regarded as unsafe and could lead to *'an increase in radiation incidents'*, most likely as a result of increased pressures and mental and physical strain.

Figure 22: Word Cloud of Common Responses Regarding Barriers to CT Imaging (Ireland)

In SSA, 42% of respondents who opted to answer this question mentioned insufficient maintenance in the region, one radiographer stating, *'it takes over 4 weeks to repair the CT machine',* and another stating *'it took almost 3 months to acquire the new CT tube'*. This highlighted the extent to which service engineer shortages may be affecting healthcare facilities in SSA. Considering a majority of the facilities in SSA (62%) had only one CT scanner, such significant downtimes would have had a substantial effect on access to CT imaging. A further 17% of respondents in SSA commented on unstable electrical supply, an additional 17% mentioning radiographer shortages, again radiographers in SSA less concerned with staff shortages than radiographers in Ireland. Two respondents in each region mentioned a shortage of radiologists to report on CT scans, likely because radiographers in SSA are often expected to deliver results in their absence (Kawooya, 2012).

One respondent from each region who was working in private practice reported their facilities did not face many challenges, one radiographer stating, *'our waiting lists aren't bad, we are well staffed, and people are usually glad to get their scan'*. A separate respondent commented on the high purchasing price of imaging equipment, stating this '*affects availability and accessibility to patients needing CT scans'*. In this section, a respondent in SSA claimed some patients in rural settings must *'travel almost 5 hours to get CT services'*. This is a point of grave concern as many acute conditions would have worsened by the time that patient accessed necessary imaging and received appropriate treatment (Figure 23).

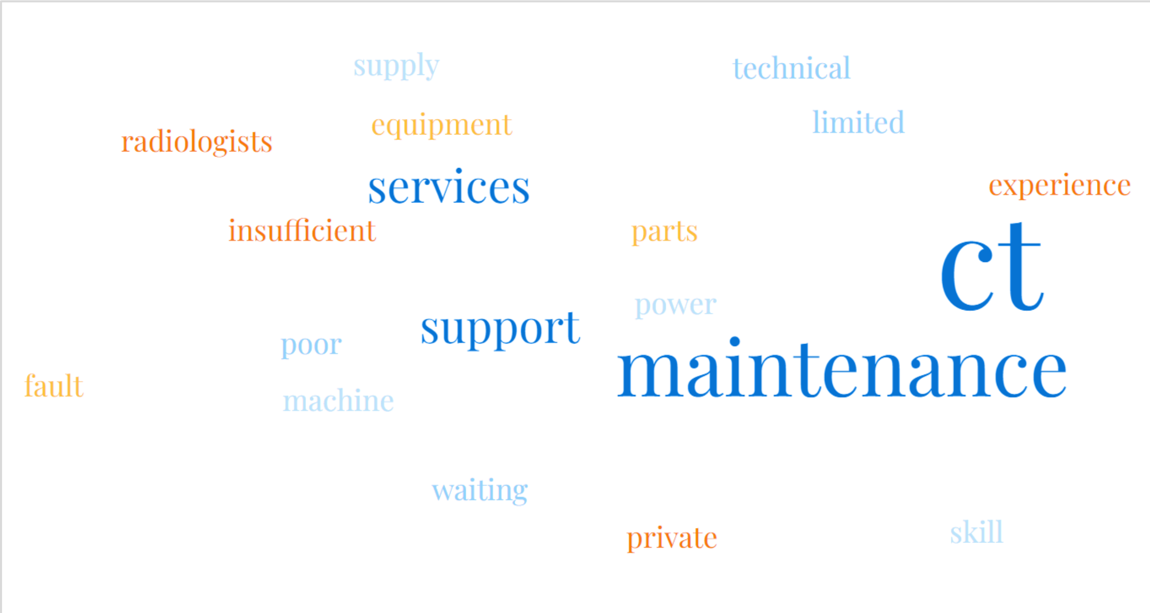

Figure 23: Word Cloud of Common Responses Regarding Barriers to CT Imaging (SSA)

4.3. The User Experience of CT Radiographers

Several questions were posed to assess the user experience of the CT radiographer, from confidence levels to specific task assessment.

4.3.1. Radiographers' Confidence Levels

Most radiographers expressed some level of confidence when performing CT scans, as varying levels of confidence were reported with a majority (52%) reportedly 'very confident', 40% 'confident' and just 8% 'somewhat confident'. As expected, confidence levels increased with increased years of experience, most respondents rating themselves 'very confident' having greater than ten years of experience (Figure 24). 50% of those reportedly 'somewhat confident' had 0-1 years of experience, and the other 50% had 1-5 years of experience. Chi-squared analysis revealed a statistically significant difference between years of experience and radiographers' confidence levels, with an exceptionally low p-value of 1.96E-7. This indicates that the radiographers who declared relatively low confidence levels should improve with more experience, as expected.

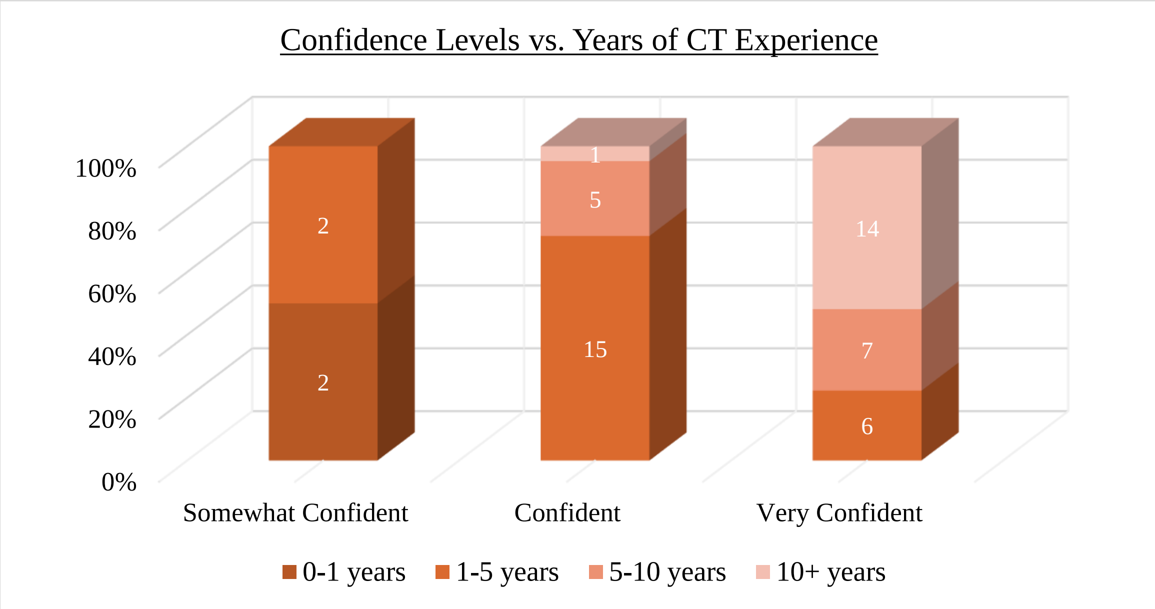

Figure 24: Confidence Levels vs. Years of Experience in CT

No respondents from either region rated themselves 'not very confident' or 'not confident at all' which is reassuring given that CT radiographers are delivering relatively high radiation doses to patients (Kazemi *et al.*, 2023). When respondents were invited to elaborate on their response to this question, they most often mentioned their years of experience in CT imaging and their depth of knowledge regarding imaging protocols. Five respondents (17%) described their time working in isolation, one stating *'I tend to work alone sometimes, and this has helped me build confidence'*, re-iterating the need for radiographers to have a smooth user experience as they are often expected to operate CT systems alone. While most radiographers claimed to be at least somewhat confident, some reported a lack of confidence when undertaking less-routine examinations, stating *'protocols change regularly which can be difficult'*, *'would have to consult department protocol book before scanning'*, and *'still need training on a few procedures'*.

Respondents in both regions expressed feelings of complete confidence and uncertainty, suggesting a diverse range of experiences and comfort levels, as expected with any profession. Potential reasons for these polarised sentiments could be different for each region; for example, staff shortages and increased pressures may affect the ability of radiographers in Ireland to be completely confident, whereas perhaps outdated and semi-dysfunctional equipment in SSA may affect a radiographer's ability to be completely confident. However, respondents who answered this question most often commented on their reasons for being confident rather than the opposite, commenting, *'there's not a lot I haven't seen or had to scan', 'over the years I have seen and performed a wide range of scans'*, and *'I am confident with… how to get the best for each patient with their scans'.*

4.3.2. CT System User Interface: Usability Assessment

Participants were later asked to read ten statements around their interactions with the CT system's user interface, before selecting a response; strongly disagree, disagree, neutral, agree and strongly agree. This question would help streamline specific areas for system improvement. Overall, the majority of participants agreed or strongly agreed with each statement, indicating general satisfaction with task performance using their system's user interface. Radiographers agreed they could easily select the appropriate patient for each scan, there were sufficient imaging protocols to suit most of their needs, they could easily navigate through protocols to make the most appropriate selection, they could make appropriate changes to exposure parameters before commencing a scan, there were sufficient exposure parameter options to accommodate various requirements, the images they produced were consistently technically diagnostic, they could easily navigate their user interface to perform necessary post-processing tasks, they could perform multiple consecutive scans without the user interface becoming unresponsive, and that their CT system software integrated well with other platforms.

In SSA, respondents were relatively more satisfied with their ability to navigate the user interface to perform each of these tasks when compared with those in Ireland (91% agreed or strongly agreed in SSA, and 83% agreed or strongly agreed in Ireland). Both parties, however, indicated a generally positive user interface experience, suggesting the user interfaces are broadly meeting the needs of those in developed and developing countries, and that CT system manufacturers could be standardising their user interface designs to meet the needs of diverse users. However, perhaps complete satisfaction could be achieved through localised customisation of user interfaces, for example, with increased language options or tailored training materials. Responses to this question were divergent, the task rendering the most dissatisfaction in Ireland that radiographers could appropriately select the correct patient for each examination, and that there were sufficient pre-set imaging protocols to suit most of their needs. However, responses to this question either strongly disagreed, agreed, or strongly agreed, with no responses in between (Figure 26). In SSA, the most notable dissatisfaction was with the ability to perform consecutive scans without experiencing software malfunctions, which may again allude to infrastructural challenges

(Figure 27). No respondents in SSA answered 'neutral' at any point, indicating relatively strong feelings toward each of the tasks outlined.

Respondents in Ireland were relatively less satisfied with their user interface interactions than those in SSA, with 12% indicating disagreement or strong disagreement and 5% neutral. This is compared with 9% of respondents in SSA indicating disagreement or strong disagreement, and none answering neutral. 90% of respondents in Ireland were satisfied the projected patient dose was clearly visible to them prior to commencing the CT scan, compared with 81% of respondents in SSA. 19% of respondents in SSA were dissatisfied the projected dose was visible to them before commencing their scan, and although a minority, perhaps making this feature more prominent could help these radiographers to better comply with regulatory standards and avoid radiation incidents, a concern previously raised.

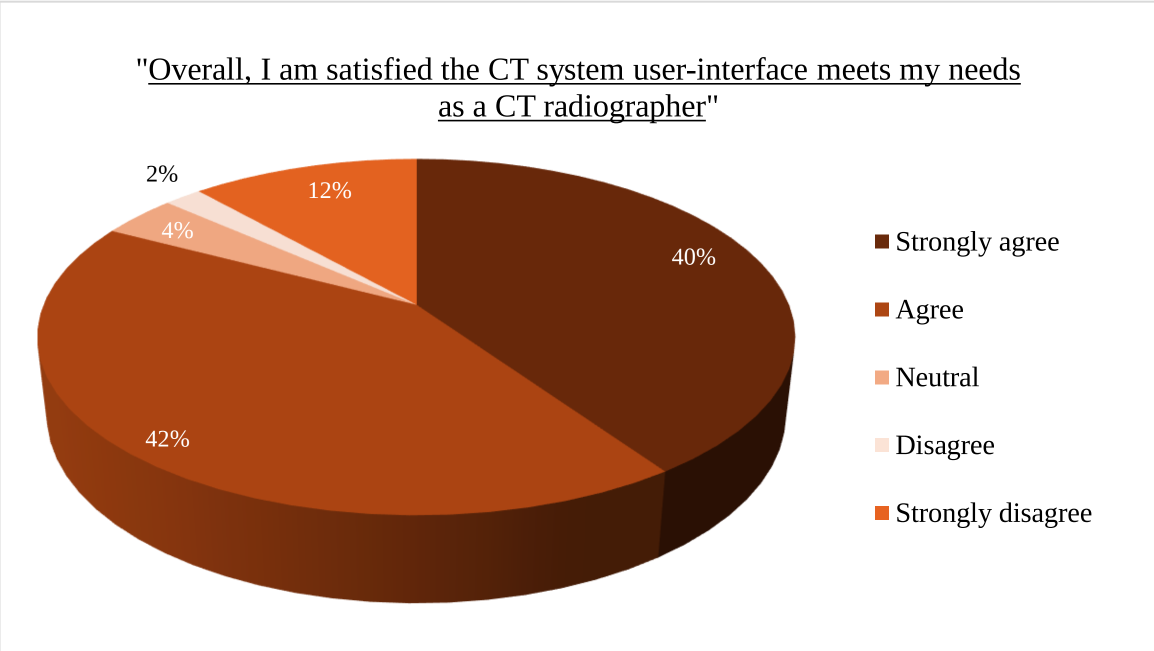

Figure 25: Participants' Satisfaction with CT System User Interface

When asked to rate overall satisfaction with the CT user interface, 82% of respondents indicated satisfaction that the interface meets their needs. 78% of respondents in Ireland were satisfied the CT system user interface meets their needs, 3% remained neutral, and 19% strongly disagreed that the interface meets their needs. Again, respondents in SSA were relatively more satisfied the CT system user interface meets their needs, with 90% indicating some level of satisfaction, 5% remaining neutral, and 5% disagreeing. None of the respondents in SSA strongly disagreed that the CT system user interface meets their needs (Figure 25).

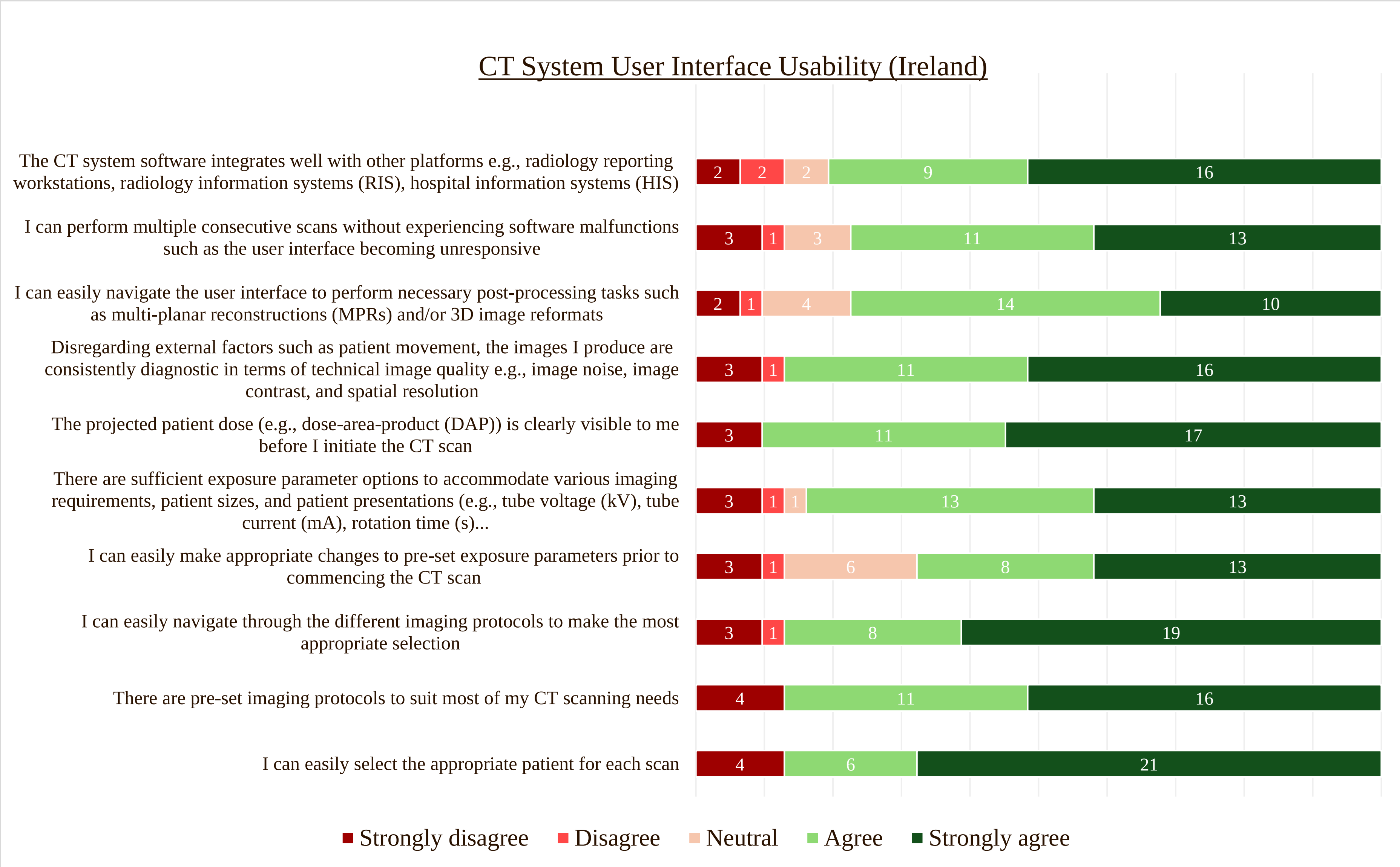

Figure 26: Likert-Scale Analysis of CT System User-Interface Usability (Ireland)

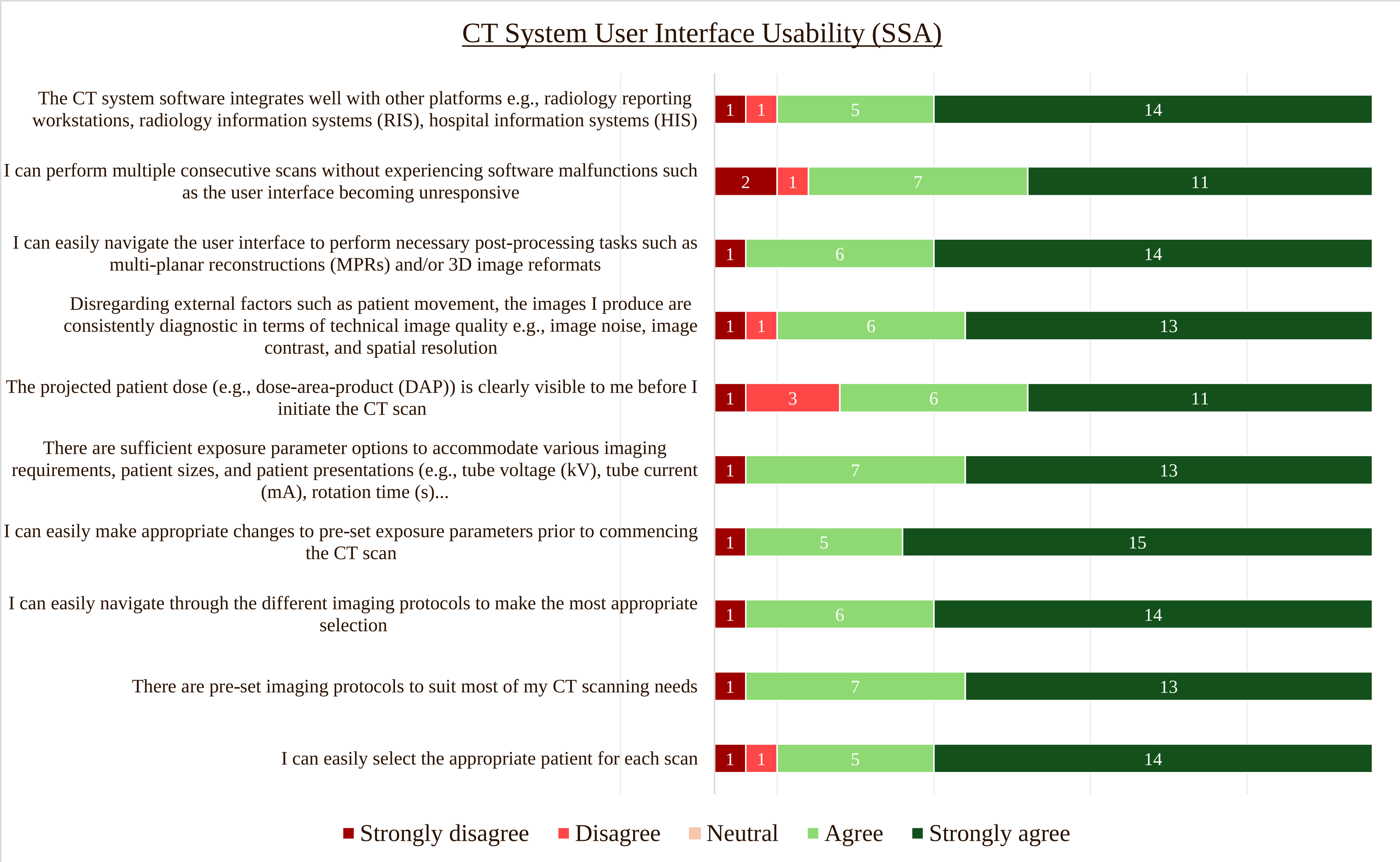

Figure 27: Likert-Scale Analysis of CT System User-Interface Usability (SSA)

4.3.3. Open Question Analysis of CT System User Interface Interaction

When asked to elaborate on their experiences with the CT system user interface, and any challenges they had faced, 63% of respondents chose not to answer this open question. 19 participants, however, provided rich contextual information, reporting issues such as *'equipment malfunctioning', 'issues with responsiveness', 'slow acquisition time', 'applications freezing'*, and *'software interface tends to lag at times'*. Others commented on issues with *'reformats, 'reconstructing', 'multi-planar reconstructions'*, and *'post-processing'*. Two respondents mentioned issues with network and integration, stating *'network issues can cause delays'* and *'transfer rate of processed images to PACS [Picture Archiving and Communications System]… can cause a bottleneck'*. Three respondents praised Siemens Healthineers AG in this section, one stating *'they have an excellent user interface',* the other two respondents comparing Siemens Healthineers AG to other manufacturers, *'the whole scanning process is much more time consuming than with Siemens'*. Another respondent praised Siemens Healthineers AG for hiding technical parameters behind simpler tabs/names to avoid confusion and reduce mental strain. Some respondents identified specific areas for improvement, criticising their system's user interface for *'a lot of clicking'* and for being *'confusing to users (particularly those with less experience)'*.

4.3.4. CT Scanner Hardware: Usability Assessment

Participants were later asked to read six statements regarding their CT scanner hardware interactions before selecting a response; strongly disagree, disagree, neutral, agree and strongly agree. This would identify specific areas for improvement in the CT scanner hardware design. Again, most participants indicated agreement or strong agreement with each statement (75% in Ireland and 86% in SSA), again indicating an overall satisfaction among radiographers. Respondents were satisfied they could easily navigate the control panel buttons, adjust the patient table and/or gantry position, view and monitor the patient before, during and after scanning, and communicate with the patient before, during and after scanning. Overall, they were also satisfied that their CT scanner could physically support the weight of each patient encountered in their healthcare facility and that they could perform multiple consecutive scans without experiencing scanner hardware malfunctions. In Ireland, respondents were approximately 11% less satisfied with their scanner hardware interactions than with their CT system user interface interactions, relatively speaking. Respondents in SSA were approximately 6% less satisfied with their CT scanner hardware interactions relative to their CT system user interface interactions.

Respondents in Ireland were less satisfied with their CT scanner hardware compared with respondents in SSA, 16% indicating disagreement or strong disagreement with the listed statements, and 9% remaining 'neutral' (Figure 29). In SSA, just 8% of respondents expressed disagreement or strong disagreement with the listed statements, and 6% remained neutral (Figure 30). In Ireland, the statement eliciting the most disagreement (23%) was that radiographers could easily view and monitor their patients before, during and after their scan. This suggests that almost a quarter of radiographers feel there are challenges in maintaining patient visibility throughout the scanning process which could have a major effect on patient safety. This could be due to the scan room layout, or to dysfunctional or absent gantry cameras, for example. 19% of respondents in Ireland disagreed that their scanner hardware could physically support the weight of each patient encountered, compared with 10% of respondents in SSA. This is most likely an indication that patients in Ireland are more likely to exceed scan table weight limits, and not that the scanners in SSA are more robust, as Ireland has a higher prevalence of obesity when compared with SSA (HSE, 2024b).

In Ireland, 16% of respondents disagreed to some level that they could perform multiple consecutive scans without experiencing scanner hardware malfunctions, whilst 13% disagreed they could easily monitor the patient before, during and after scanning. 77% of respondents, however, agreed they could easily monitor the patient during these times, which again is crucial for patient safety. These figures indicate most radiographers are confident in their ability to maintain patient safety while scanning, however, some improvements may be necessary such as advanced monitoring systems or improving the robustness of existing scanner gantry camera systems. The response eliciting most disagreement in SSA was that they could perform multiple CT scans without experiencing scanner malfunctions, similar to their response to user interface interactions, 14% disagreeing with this statement. Respondents in this region were satisfied they could communicate with patients before, during and after scanning (95%), and that they could easily adjust the table and/or gantry position (95%), these actions rendering the greatest satisfaction both in Ireland and in SSA.

When asked to rate their satisfaction with the CT scanner hardware directly, 71% of respondents in Ireland were satisfied with their CT scanner hardware, which was 7% less than were satisfied with their CT system user interface. 13% of respondents in Ireland remained neutral, and 16% indicated some level of dissatisfaction with their scanner hardware. Again, respondents in SSA were relatively more satisfied than those in Ireland, 81% indicating some level of satisfaction with their scanner hardware, whilst 19% of respondents remained neutral and no respondents indicated dissatisfaction with their scanner hardware. The lack of dissatisfaction in SSA respondents contrasted with 16% dissatisfaction in Ireland which may indicate certain regional differences in experience and expectation. Overall, 82% of respondents were satisfied the user interface meets their needs, whilst 77% were satisfied the scanner hardware meets their needs. Both depict generally positive experiences, whilst the 5% less satisfaction with scanner hardware may indicate a greater need to invest in solutions to improve same.

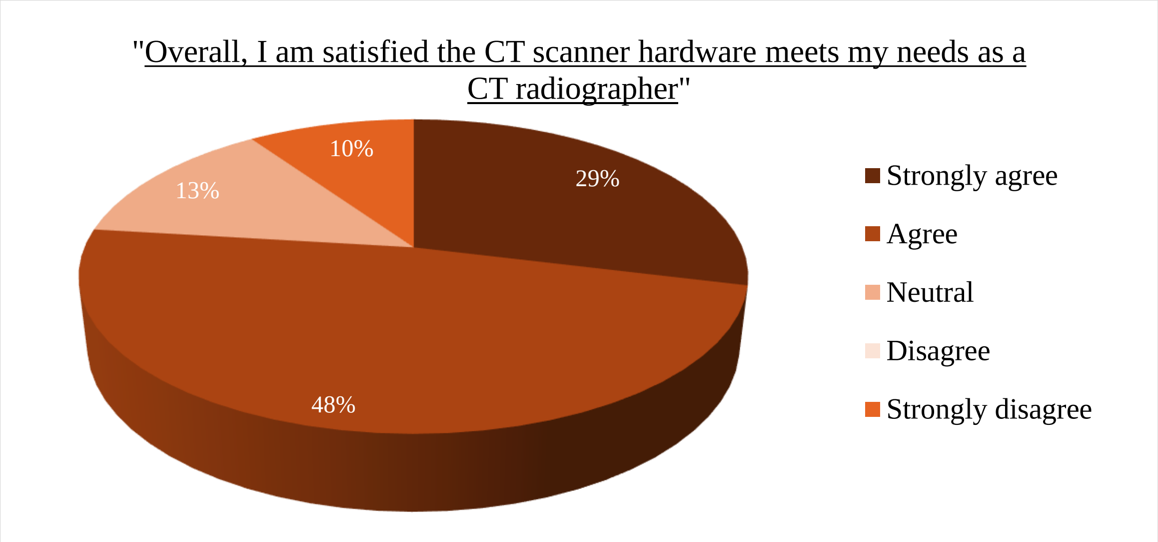

Figure 28: Participants' Satisfaction with CT Scanner Hardware

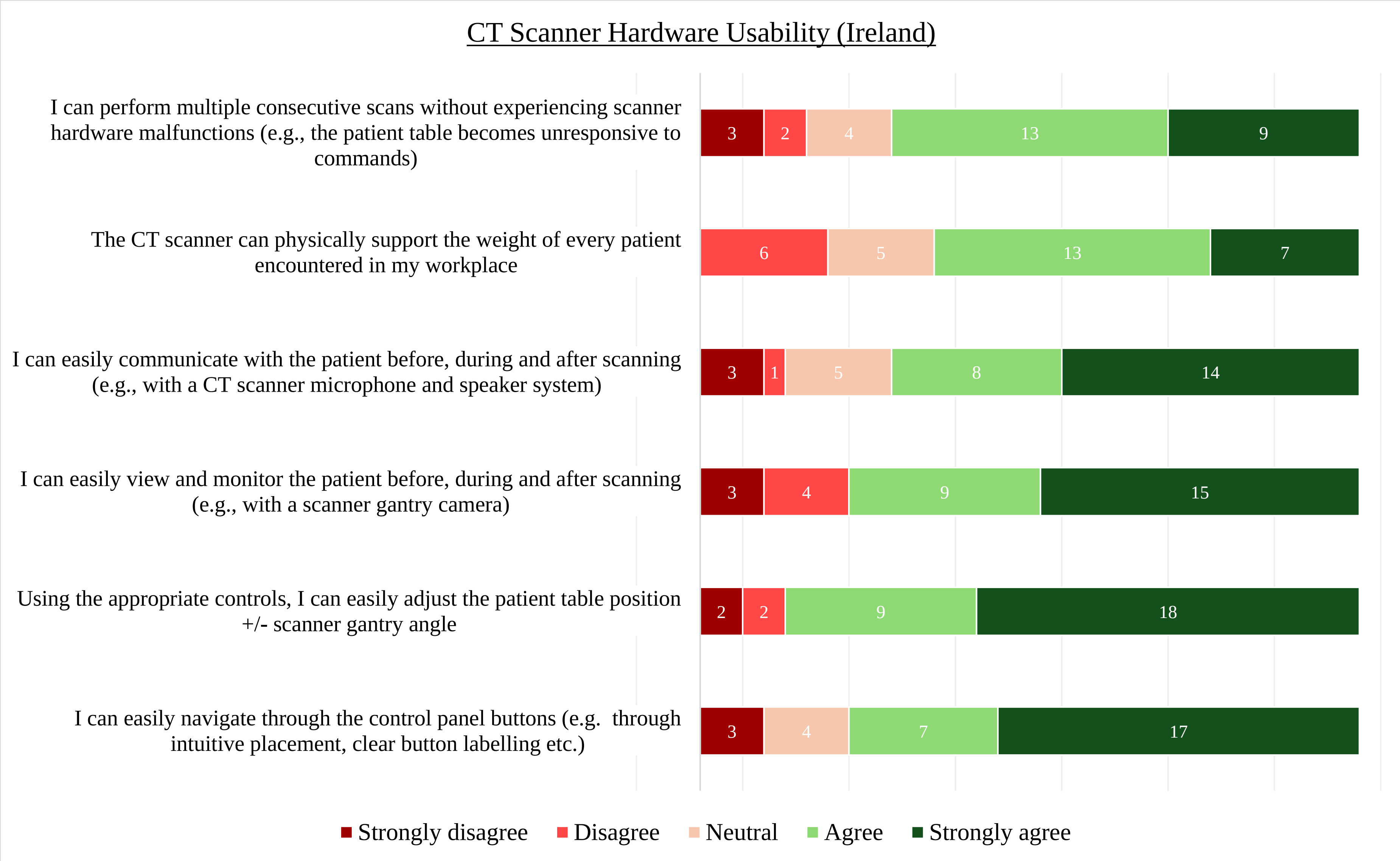

Figure 29: Likert-Scale Analysis of CT Scanner Hardware Usability (Ireland)

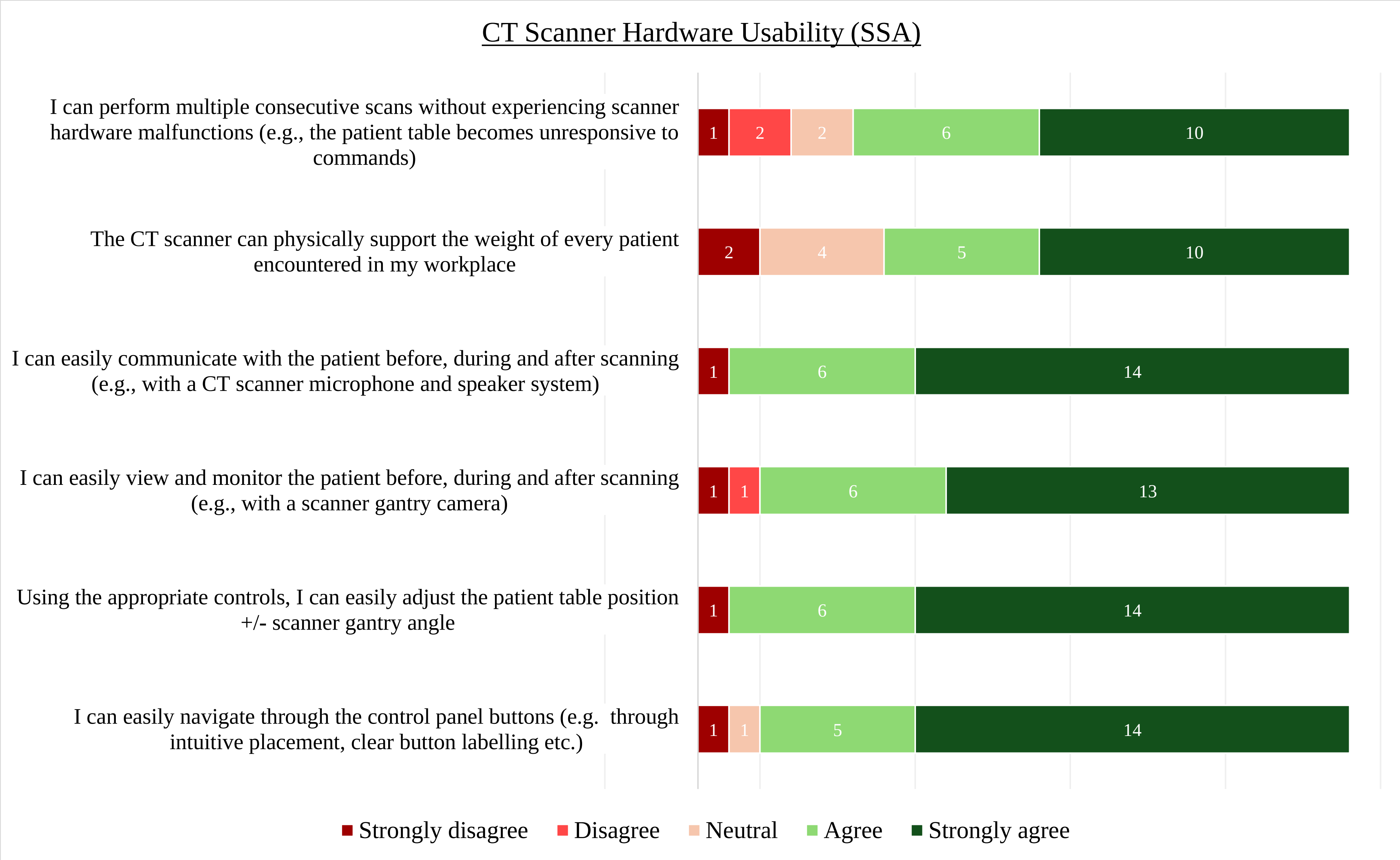

Figure 30: Likert-Scale Analysis of CT Scanner Hardware Usability (SSA)

4.3.5. Open Question Analysis of CT Scanner Hardware Interaction

42% of respondents commented on a specific challenge they had encountered with their CT scanner hardware. 59% of those who responded reported issues related to scan table weight limits and scanning heavier/bariatric patients. Six respondents reported that even some patients within the stated weight limit encountered difficulties due to a specific body habitus, underscoring the need to revise scanner hardware design for a diverse range of patients. Frequent challenges with patient body habitus or weight limits can threaten the efficiency of an imaging department, and also raises concerns around patient comfort and dignity during positioning. One respondent commented *'wear and tear has prohibited the table weight to a maximum of 140kgs'*, indicating a local but substantial issue, another commenting *'gantry bore size in the country is a challenge for obese and large patients'*, speaking to Ireland (Figure 31). This issue was not unique to bariatric patients, one respondent criticising the ability to position patients who are under the table weight limit within the gantry, specifically those with kyphosis.

Siemens Healthineers AG received praise in this section, in particular for their *'out and down button in user control panel in scan room'*, which enables radiographers to move the patient out of the scanner from inside the control room. This can improve efficiency and reduce anxiety in patients. Other issues included faulty speakers (3), power cuts (1), slow scan reconstructions (1), and dysfunctional gantry cameras (1) Complaints received from both regions were similar, mostly referencing scan table limitations and faulty speakers.

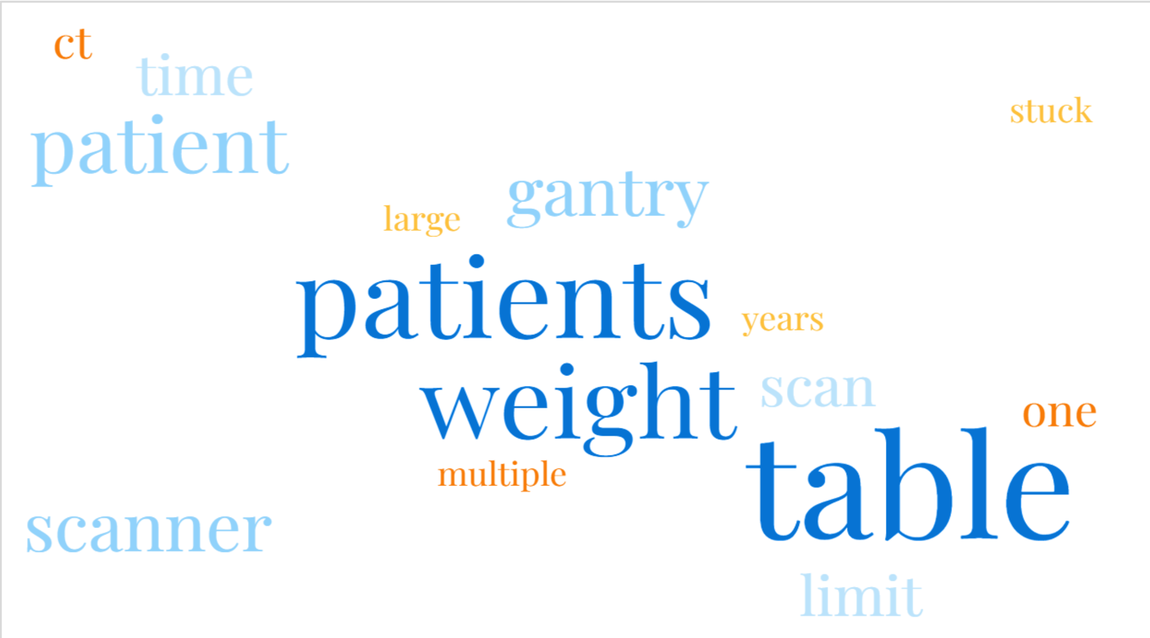

Figure 31: Word Cloud of Common Responses on Challenges With Scanner Hardware (Overall)

Participants were invited to comment on a specific scan failure, malfunction, or unanticipated downtime they had experienced, with 44% of respondents opting to answer this question. Four respondents mentioned issues with their CT scan table, an additional three expressing concerns around inadvertent radiation exposures delivered during scanner malfunctions. Respondents commented *'the screen froze', 'scan stopped mid-way', 'table stopped moving in the middle of a scan resulting in repeated imaging on a different scanner'*. Other respondents commented on CT scanner downtime while awaiting maintenance, *'part of the hardware in the scanner broke ... leading to 4 days downtime', 'engineers often take a couple of days to come to fix issues'*, and *'downtime due to lack of skills in… local engineers'*. Specific hardware issues were also mentioned, including *'a faulty detector element', 'camera for positioning', 'contrast in mylar window', 'tube needing replaced', 'tube malfunction'*, and *'scanner overheating'* (Figure 32).

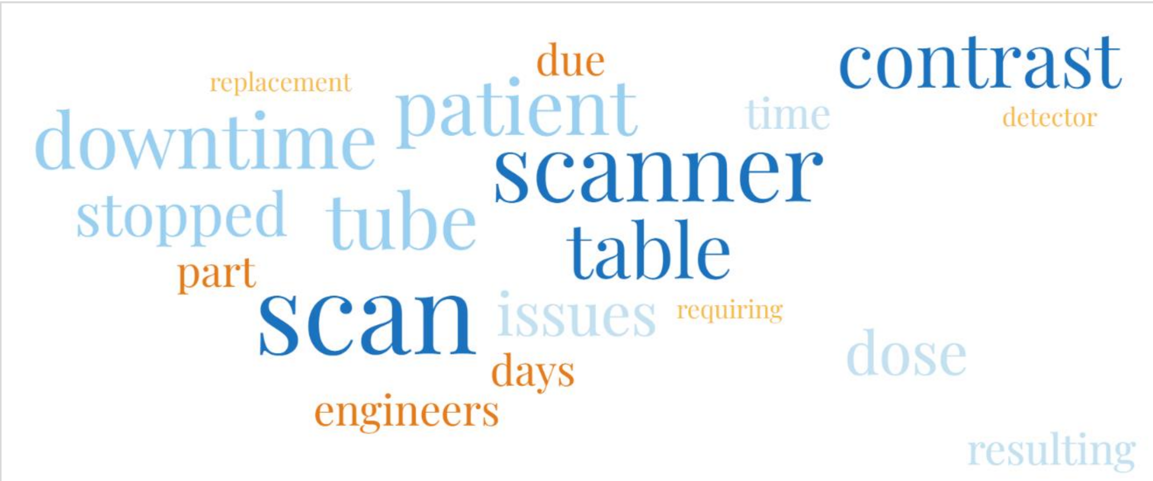

Figure 32:Word Cloud of Common Responses on Scan Failures, Malfunctions and Downtimes (Overall)

4.3.6. Closed Question Analysis of Issues Related To CT

Participants were then presented with ten CT system related issues and asked to rank them in order of frequency of occurrence, with an aim to discern the urgency with which these issues should be addressed in each region. Overall, scanner hardware issues appeared most frequent, with 67% of respondents ranking this in the top four most frequently occurring issues (Figure 33). When the data are further stratified, scanner hardware retains its relatively high ranking as one of the most frequently occurring issues, 26% of respondents in Ireland ranking this as their number one most frequent issue (Figure 34). In SSA, hardware issues are not as highly ranked, though 48% of respondents in this region rank this in the top three most frequently occurring issues (Figure 35). Again, regulatory issues appeared to have little impact on radiographers in Ireland or SSA, receiving the lowest ranking in both regions.

In Ireland, software issues causing scanner malfunction and patient condition leading to scan failure ranked highly, with 55% and 45% in the top three rankings, respectively. Of little significance in Ireland was supply shortage causing scanner downtime, with 74% of respondents ranking this seventh or lower. This was of greater significance in SSA, as expected, with 52% of respondents ranking this in the top five most frequently occurring issues. This again highlights disparities in resource availability between developed and developing regions, and the subsequent prioritisation of need. Similarly, 48% of respondents in SSA ranked unexpected maintenance causing scanner downtime in the top five most frequently occurring issues. However, a more significant 58% of respondents in Ireland ranked this in the top five most frequently occurring issues, which is surprising given the issue with maintenance in SSA, though this likely reflects the high relative frequency of the other issues in SSA. For example, 76% of respondents in SSA ranked environmental issues causing scanner malfunction in the top three most frequently occurring issues, compared with 39% of respondents in Ireland. While these findings implicate environmental issues as an important issue in both regions, their higher prevalence in SSA highlights them as more critical and alludes to more significant infrastructural issues in SSA than in Ireland, as described in the secondary research. This may indicate a need for targeted improvements in environmental controls and infrastructural support in CT system designs for developing regions.

Moderate concern was shown for operator error and patient miscommunication in Ireland, these issues ranking less frequent in SSA, in which failed contrast injection was also of little concern when compared with Ireland. Failed contrast injection appeared to be of relatively high concern in Ireland, 65% of respondents ranking this in the top five most frequently occurring issues at their workplace. This may reflect differences in clinical practice, available resources, and even training between the two regions. For example, perhaps contrast enhanced CT examinations are performed more frequently in Ireland, leading to more frequent challenges. Again, this may also indicate the relative frequency associated with the other listed issues in SSA, and their relative infrequency in Ireland.

Overall, the findings suggest significant differences between Ireland and SSA in terms of issue frequency and impact. Scanner hardware issues emerged as the most frequent issue in both regions, though relatively more frequent in Ireland than in SSA. Respondents in SSA showed greater concern for supply shortages and environmental issues, pointing toward their broader infrastructural challenges that may need focused attention. Operator error and miscommunication with patients remain moderate concerns in Ireland, and are relatively less significant in SSA, where failed contrast injection is also of less concern. These findings underscore the need to implement region-specific strategies that address the unique challenges facing radiographers in diverse contexts of use, to enhance the user experience and to improve access to CT, enhancing overall efficiency and ensuring more patients can receive appropriate care.

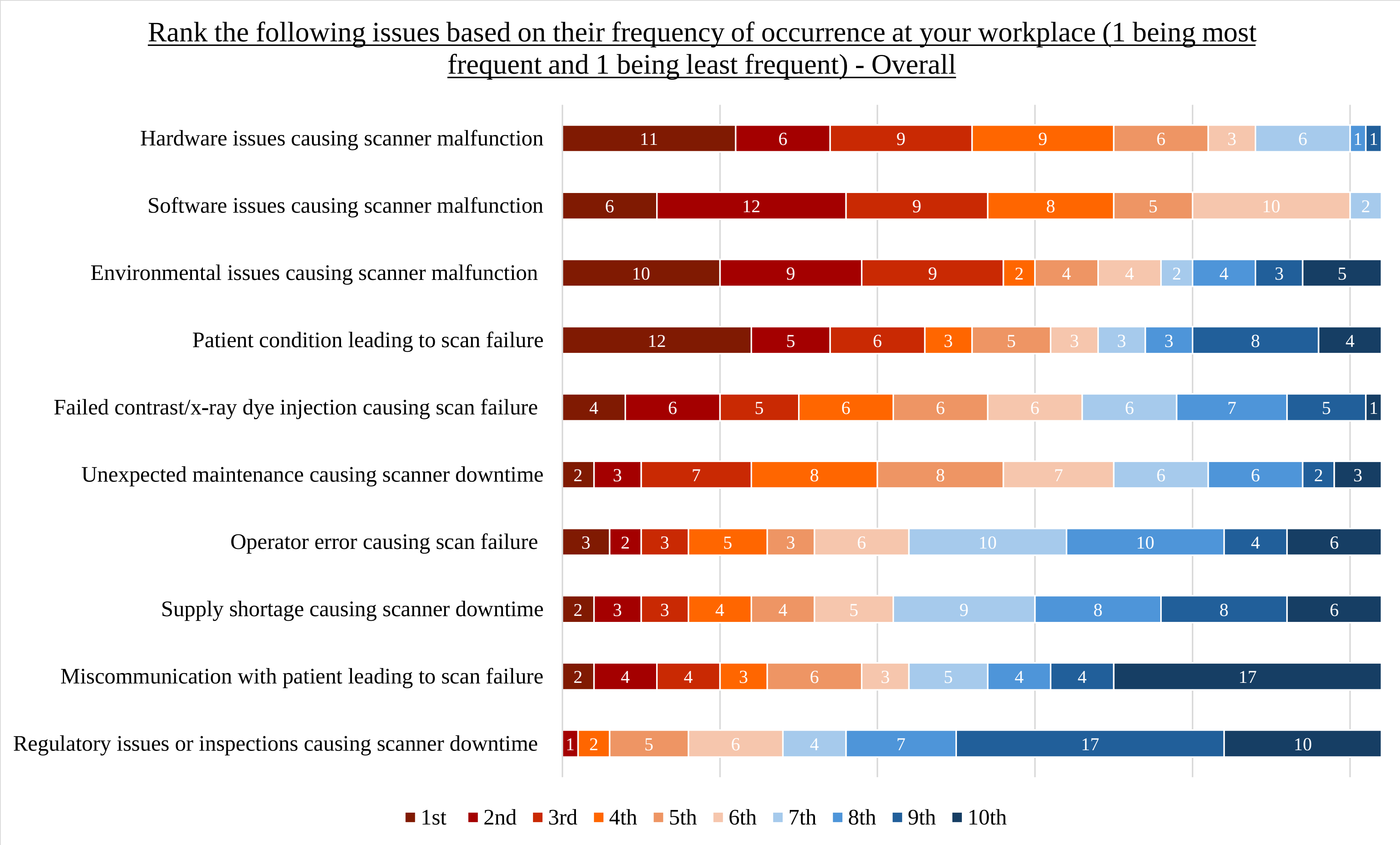

Figure 33: Ranking the Most Frequently Occurring Issues in CT Imaging (Overall)

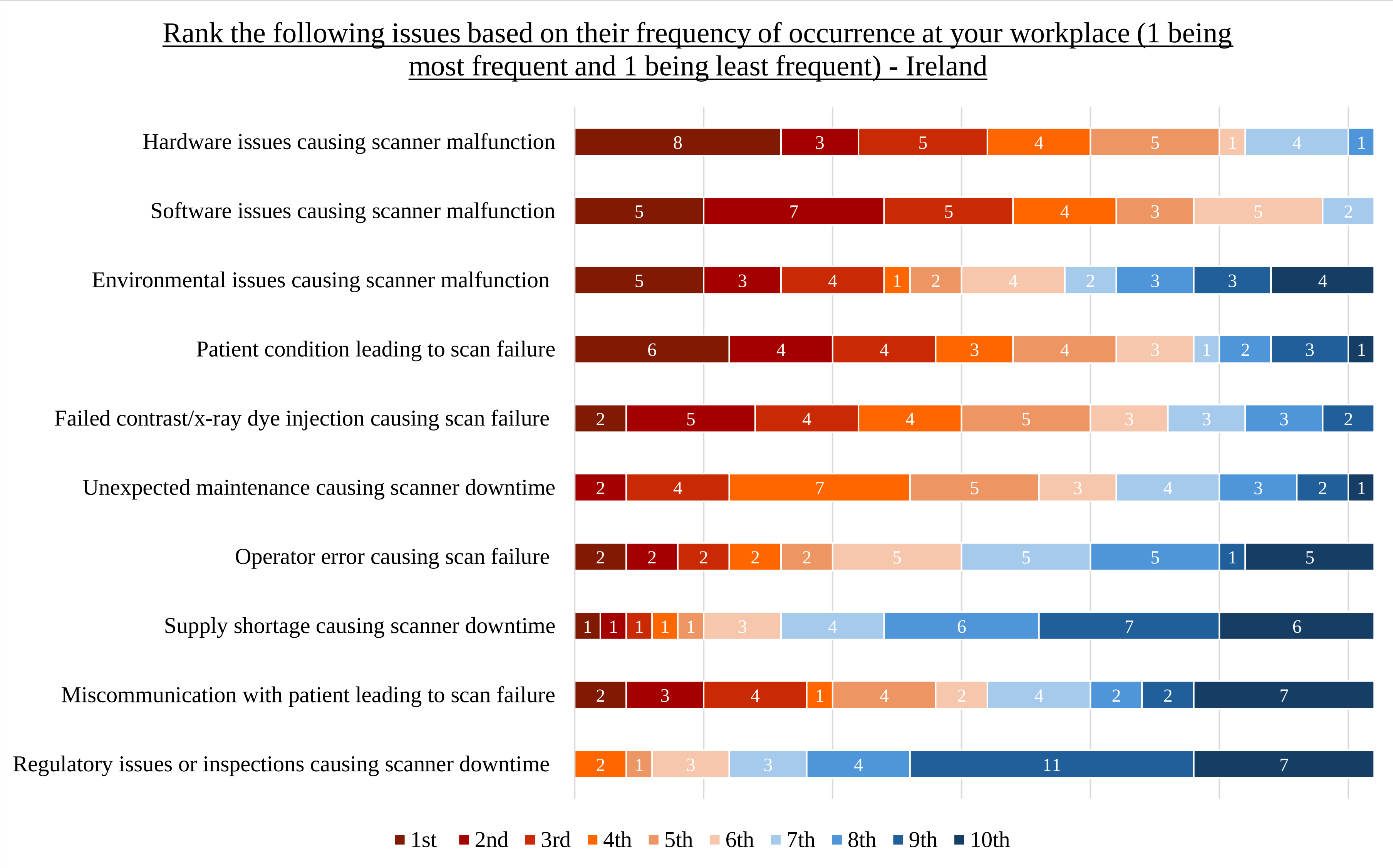

Figure 34: Ranking the Most Frequently Occurring Issues in CT Imaging (Ireland)

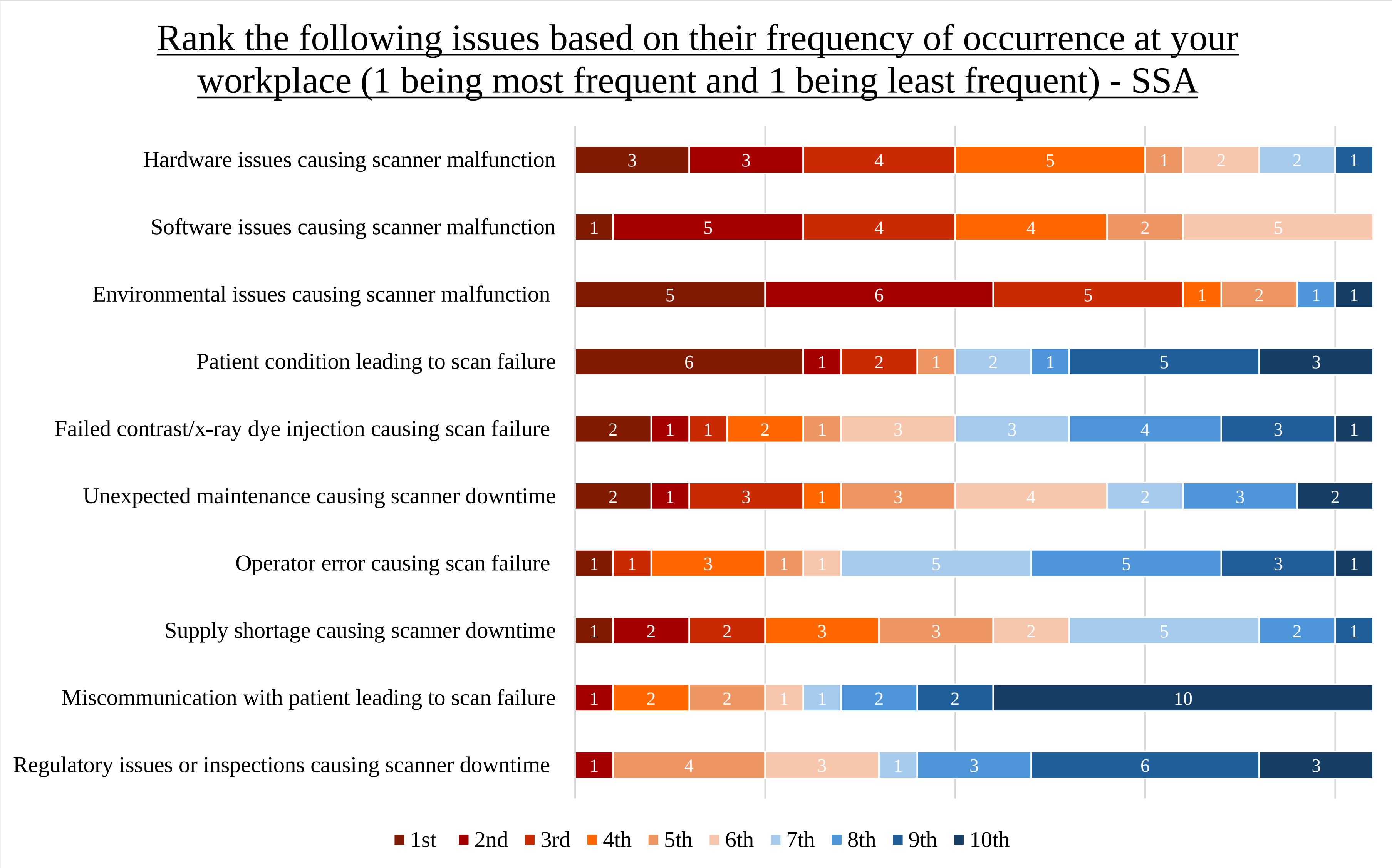

Figure 35: Ranking the Most Frequently Occurring Issues in CT Imaging (SSA)

4.4. Participant Preferences

Several questions assessed participant preferences for CT system manufacturers and CT system features.

4.4.1. CT System Manufacturer Preferences

Participants were invited to mention a CT system manufacturer whose systems they had found most user-friendly, with 83% of the total study population choosing to respond, indicating strong feelings toward this topic. While this question remained open, only the five CT system manufacturers already mentioned were named, most likely owing to their large market shares. Just under half (49%) of respondents to this question claimed CT systems manufactured by Siemens Healthineers AG were most user-friendly, commenting *'overall nice balance between display of more technical features without overcomplicating the interface'*, and *'more efficient, especially in trauma situations where an additional phase of scanning may be required quickly'*. Another respondent called Siemens Healthineers AG their *'preferred vendor'* on account of the *'very user-friendly interface'* and *'excellent service'*. 16% of respondents to this question claimed CT systems manufactured by GE Healthcare Technologies Inc. were most user-friendly, with one respondent praising their *'easy user face and reformatting capabilities'*. Another 16% claimed CT systems manufactured by Philips Healthcare were most user-friendly, though none made additional remarks.

7% claimed CT systems manufactured by Canon Medical Systems Corp. were most user-friendly, with a further 7% praising Toshiba. However, again, none of these respondents made additional remarks. Two respondents chose to remain neutral having only ever used CT scanners from by a single manufacturer. Such response identifies Siemens Healthineers AG as a clear favourite among radiographers, suggesting the systems they manufacture greater meet radiographers' needs compared to others. The failure of respondents to leave specific comment on Philips Healthcare, Canon Medical Systems Corp. and Toshiba indicates that whilst these manufacturers are favoured by some, they may not stand out in the same way that Siemens Healthineers AG and GE Healthcare Technologies Inc. do (Figure 36).

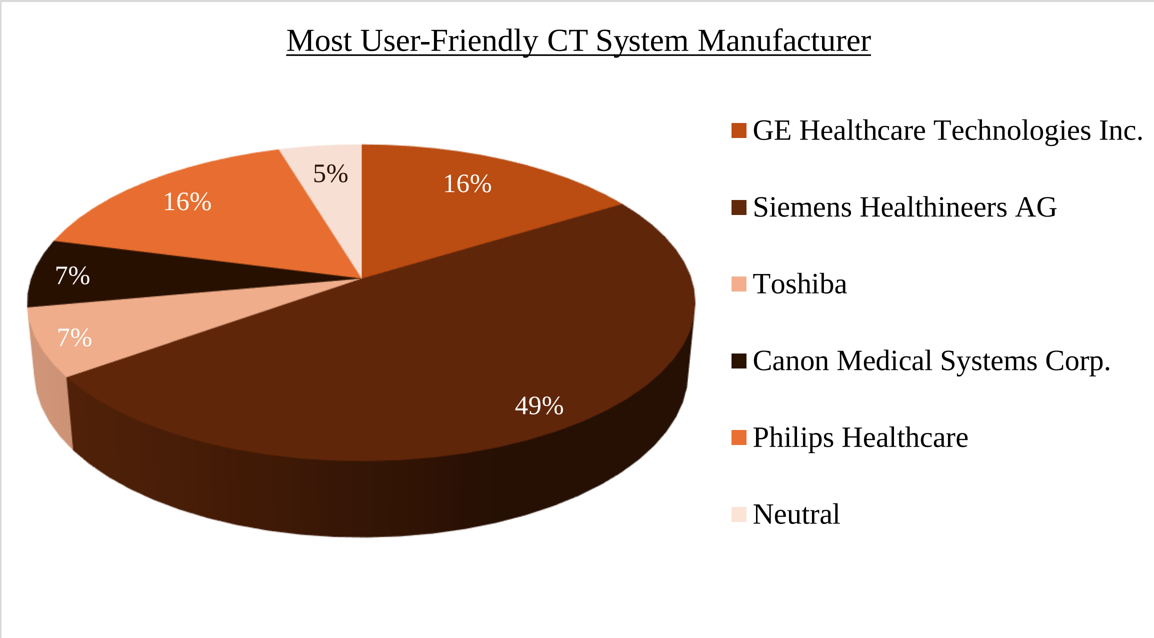

Figure 36: Most User-Friendly CT System (Overall)

4.4.2. CT System Feature Preferences

Radiographers were asked to comment on specific features they feel could enhance their CT scanning experience, with respect to the system user interface and the CT scanner hardware. With regard to the CT system user interface, 25% of respondents suggested GE Healthcare Technologies Inc. should make their user interface more accessible, one respondent commenting *'GE could organise the grouping of icons/functions on 3D/MPR interface into a number of clearer selectable options such that not every icon is viewable on screen all of the time'*, and another *'the system we use (GE) is quite complicated… training can take a while'*. A further 25% of respondents suggested improving the overall ease of image reconstruction, one respondent suggesting automated 3D reconstructions for extremities could be useful. Respondents from both regions referenced issues in scan set-up, one suggesting, *'making it easier to assign correct examination when multiple scans on same patients'*, another suggesting *'less clicking to change scans or add/delete phases of scans'*, both comments alluding to a desire for more flexibility when selecting scan protocols. Other respondents requested more paediatric protocols or the inclusion of local languages to accommodate a broader range of patients.

With regard to the CT scanner hardware, 38% of respondents commented on the scanner table and 25% on the scanner gantry. Respondents asked for *'a larger gantry', 'a foot control on all scanners to move the bed out and down'*, and *'possibility of angling gantry more than 15 degrees to exclude lens of the eye'*. Another respondent asked to be *'able to* *manually control the CT table and gantry movement from the console'*, a feature another respondent had praised Siemens Healthineers AG for providing. Another respondent criticised the aforementioned *'cameras for AI-guided patient positioning',* claiming these can slow down the overall process instead of improving efficiency.

Participants were then presented with ten CT system features/aspects and invited to rank them in order of importance, one being most important and ten being least. Overall, 46% of respondents ranked image quality as the most important CT system feature, with 67% ranking this in the top three (Figure 37). This sentiment was shared by radiographers in Ireland and to a lesser extent in SSA, with 77% of respondents in Ireland ranking image quality in their top three compared to 52% in SSA (Figure 38, Figure 39). The relatively higher prioritisation of image quality in Ireland may be reflective of the prioritisation of other factors in SSA, including cost effectiveness which was ranked number one by a third of respondents. This prioritisation of basic needs over image quality may be driven by the significant resource constraints reported across SSA. Respondents in Ireland also valued cost effectiveness, to a lesser degree, ranked second or third-most important by 19% of respondents. Radiation reduction capabilities were also rated highly overall, as expected, with 50% of respondents ranking this in the top three most important features. Again, respondents in Ireland ranked this feature more highly, with 61% of respondents ranking this in the top three compared with 33% in SSA. Reasons for this are presumably similar to those for the image quality ranking, with respondents in SSA placing greater value on factors including cost effectiveness and ease of maintenance and technical support.

29% of respondents in SSA ranked ease of maintenance and technical support the first, second, or third-most important feature, compared with 19% of those in Ireland. This matches previous findings that radiographers in SSA endure frequent scanner breakdowns and lengthy downtimes due to regional service engineer shortages. Neither region valued teleradiology and remote operation capabilities when compared with the other listed features, however, respondents in SSA showed relatively more interest than their counterparts in Ireland. Overall, 85% ranked this feature among the two least important features (94% in Ireland and 71% in SSA). Radiographers in SSA were expected to show more interest in teleradiology and remote operation owing to the increased reporting demand on radiographers in the region, however, radiographers in this region are clearly preoccupied with the more basic challenges such as cost effectiveness and technical support, before such luxuries can be afforded.

Somewhat surprisingly, a large proportion of respondents in SSA showed interest in advanced imaging capabilities despite facing more fundamental and pressing challenges, 57% of respondents ranking this in their top three most important features. This indicates that radiographers in SSA have a strong interest in technological advancement and that perhaps a more balanced approach to meeting their immediate needs while aligning with their long-term goals should be conceptualised. Respondents in SSA also valued patient comfort relatively highly, with 67% of respondents ranking this in their top five most important features. This indicates a strong commitment to improving the patient experience, compared to 32% in Ireland, respondents appearing to prioritise image quality and radiation reduction, as well as rapid scanning speed, and user-friendly operation over specific patient comfort features. Moderate regard for rapid scanning speed and patient communication was shown by radiographers in SSA.

The overall findings suggest image quality is universally regarded as the most important CT system feature, followed by radiation reduction capabilities in many cases. However, both of these statements are skewed by Irish responses, and due to the imposition of resource constraints on many countries within SSA, their priorities lie more with cost effectiveness and patient comfort. Radiographers in both regions wish to pursue advanced imaging capabilities, showing an interest in providing enhanced diagnoses. Interestingly, respondents in Ireland highly valued the user-friendliness of their CT system with 45% of respondents ranking this in the top three most important features. In contrast, just 10% of respondents in SSA placed this within their top three most important features, likely prioritising other features on account of their relatively more challenging operational environment when compared with Ireland.

Finally, respondents were asked to rate the importance of enhancing CT imaging services in their respective countries. 38% of respondents believed enhancing CT services was extremely important, 42% believed this to be very important, 12% believed this to be moderately important, the remaining 8% enhancing CT services in their country was somewhat important. Understandably, no respondent believed enhancing CT services in their country was unimportant, radiographers likely biased. Over half of respondents in SSA (52%) believed CT service enhancement in their country was extremely important, 43% believed this to be very important, and only one respondent believed this to be moderately important, with no respondents believing CT service enhancement in their country was somewhat important or not important at all. This can be compared with responses from Ireland, where 29% of respondents believed CT service enhancement to be moderately or somewhat important. This reflects an overall consensus on the importance of enhancing CT imaging services, with a higher level of urgency in SSA driven by the more pressing healthcare challenges they face when compared to Ireland.

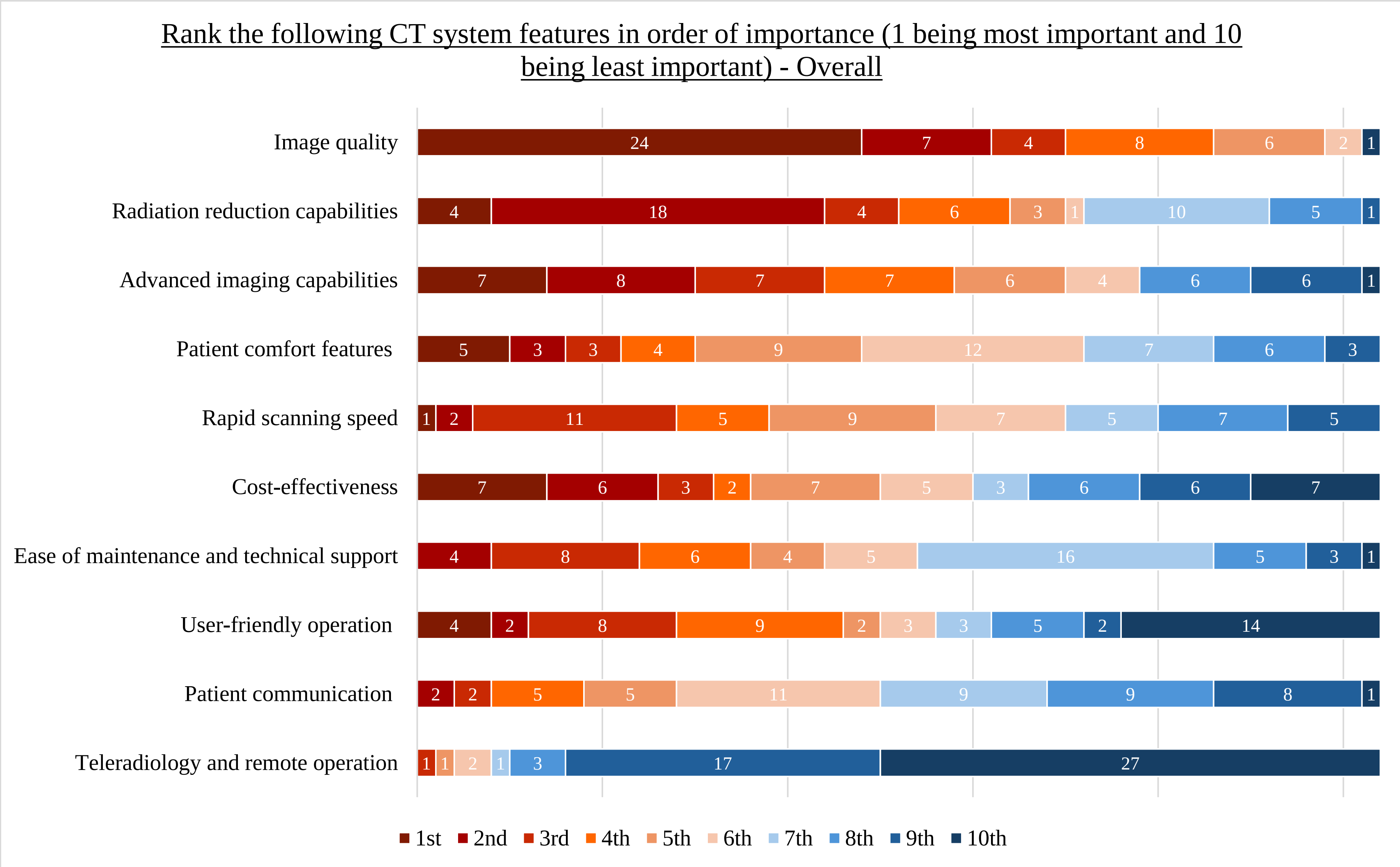

Figure 37: Ranking the Most Important Features in CT Imaging (Overall)

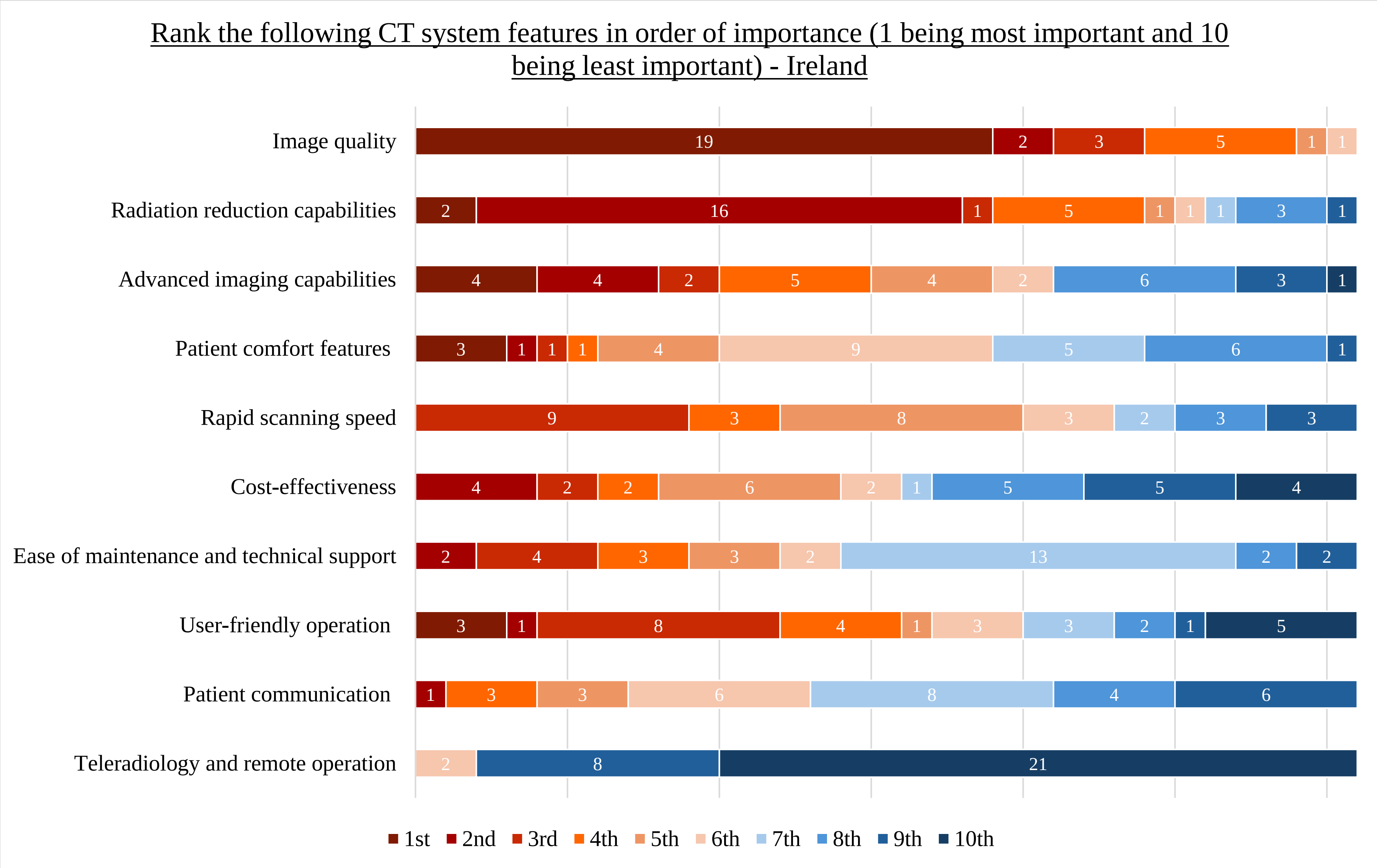

Figure 38: Ranking the Most Important CT Features (Ireland)

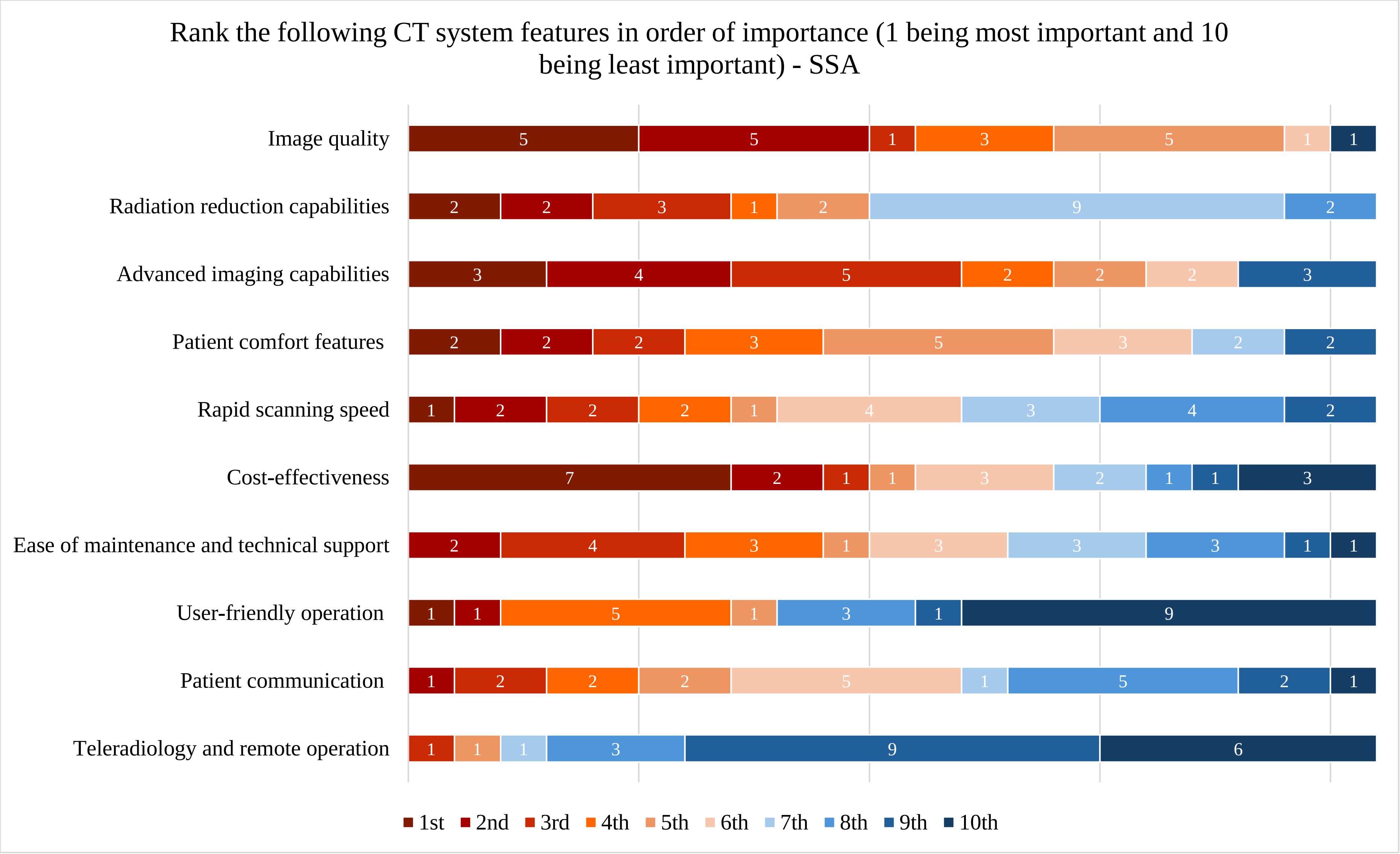

Figure 39: Ranking the Most Important CT Features (SSA)

Chapter 5: Discussion

This research aimed to assess the status of CT imaging access in Ireland and Sub-Saharan Africa and to examine the user experience of CT radiographers in both regions. The primary objective was to explore whether diverse demographic and contextual factors may influence the user experience and/or access to CT imaging services. The secondary objective was to examine whether region-specific solutions could assist in resolving access issues or other challenges uncovered within the primary research. This research was carried out with consideration for the CT imaging access disparities that exist between developed and developing countries.

5.1. Key Commonalities

Several commonalities of varying significance were observed between the two regions examined, with the most notable commonalities discussed in this section. One must note, however, that healthcare facilities in Ireland often have a second, third, or even fourth CT scanner available for use when scanner issues arise, meaning that while these issues are common, their impact on each region may differ substantially.

5.1.1. Common Demographic Factors

A similar geographic distribution of respondents was observed in both regions, with most radiographers concentrated in urban areas. The impact this could have on CT services, however, may significantly differ between regions, with an estimated 60% of the SSA population living in rural areas, compared to 31% of the Irish population (CSO, 2019; Ogunkola *et al.*, 2020). This could mean that the majority of the SSA population do not have immediate access to crucial CT imaging services and may have to travel excessive distances to access these services. These access issues are likely compounded by the apparent privatisation of imaging services in the SSA region, despite a majority of the population being without health insurance. That said, private imaging services also appeared concentrated in urban areas, no respondents reported to be working in a private and rural facility. However, it is worth noting that the high proportion of private services across SSA could increase the distance some patients must travel to receive imaging, by which time their condition may have deteriorated (Kawooya, 2012). This issue is not as pressing in Ireland as most imaging services belong to the national public health service, these findings emphasising the urgent need to increase CT scanner abundance and access to CT imaging services in SSA, to achieve equitable healthcare.

Both regions had respondents with a variety of experience levels, suggesting scanners should be flexible and intuitive as they will be used by radiographers with less than one years' experience, and by those with decades of experience. For example, those with less experience could benefit from protocol assistance features, while those with greater experience may prefer to customise their protocols and parameters for each patient. Some respondent suggestions included integrating video tutorials into CT systems to assist less experienced radiographers in decision-making, with particular consideration for the lone-working aspect of radiography. This could also be particularly useful given the staff shortages in both regions, as it minimises the time lost consulting more experienced radiographers where there is an uncertainty. That said, radiographers in both regions expressed confidence across all experience levels, proving this suggestion to be useful but low priority when compared with other issues.

In addition, radiographers in each region who worked in private healthcare facilities appeared more satisfied than those who worked in the public sector, with some open question responses indicating greater resource availability and shorter waiting lists when compared to public services. While such contentment is desirable, many radiographers subsequently opt to work in private healthcare facilities, contributing to the shortage of public sector radiographers. This appeared a common issue in both regions and requires long-term solutions such as government support and public-private partnership. Short-term solutions, however, may have a role in urgently addressing CT scanner shortages across SSA and addressing long waiting lists in Ireland, though this issue is less pressing in Ireland, as mentioned.

5.1.2. Common Scanner Condition and Acquisition Methods

Both regions declared most of their CT scanners were acquired in a brand-new condition, suggesting the frequent reported breakdowns and scanner malfunctions in SSA were not related to poor scanner condition or refurbishment. This was somewhat surprising given the breadth of research on the abundance of second-hand and refurbished equipment in developing countries (Marks et al., 2019; Global Health, 2023). Many of these studies referred to medical devices in general, the present research believing this is not prevalent in medical imaging equipment, at least in SSA.

5.1.3. Common Scanner Hardware Strengths and Challenges

The greatest difference in participants' responses were observed in the ranking of critical factors including CT access barriers, related issues, and CT system features. However, several commonalities were also noted in these rankings, one of the most significant findings of the overall study that respondents in both regions showed overwhelming satisfaction with prevailing CT systems. Respondents in Ireland and SSA expressed satisfaction that their system user interface(s) and scanner hardware suit their needs as radiographers, also expressing some level of confidence across all experience levels and educational backgrounds. Some respondents in either region identified specific areas for improvement when asked, often referencing the basic scanner components including the scan table and scanner gantry, specifically the table weight and gantry bore limits. These issues have been recognised for several years, as some researchers question whether radiology departments are equipped for rising obesity levels (Wiles *et al.*, 2017). This has historically been deemed a developing country issue, for example, one in four adults in Ireland are considered obese (IMT, 2024). However, recent economic development across Africa has led to the adoption of western cultures, including more sedentary lifestyles, meaning obesity is also rising in developing regions and scan table weight and gantry bore limits may become a universal issue if not addressed (Martey *et al.*, 2024).

The overall findings suggest that efforts to upgrade CT scanners should be focused on strengthening hardware elements such as the scan table, scanner gantry, and speaker systems. This could help reduce downtime due to hardware malfunctions and improve workflow efficiency to enable more patients to be scanned. This is considered a high priority action as hardware issues are ranked among the most frequently occurring issues in both regions, albeit more pronounced in Ireland.

5.1.4. Common Scanner Software Strengths and Challenges

Respondents in both regions reported software issues with protocol selection and image reconstruction, and difficulties with application lagging and responsiveness. Software issues were commonly ranked among the most frequent issues in both regions, after hardware issues. Respondents in Ireland were most concerned with protocol selection and image reconstruction, while respondents in SSA were most concerned with application responsiveness. While issues with responsiveness were reported in Ireland, respondents seemed less concerned by infrastructural challenges than their counterparts in SSA, indicating this issue was not particularly significant. This may be because facilities in

Ireland often have a second, third, or fourth CT scanner that can be used when such issues arise, whereas facilities in SSA generally have just one scanner for all purposes.

5.1.5. Common Access Barriers

Both regions also ranked patient condition leading to scan failure among the most frequent issues which could explain their relative interest in rapid scanning speed. Environmental issues surprisingly appeared among most frequent issues in both regions, its significance expectedly more significant in SSA, ranking the number one most frequent issue in the region. As predicted, this suggests the need to reinforce infrastructural support including electrical and network connectivity. However, this could also indicate the need for CT systems which place less demand on local resources.

5.1.6. Common Feature Prioritisation

Strengthening the fundamental components of CT scanner hardware could lay a solid foundation for integrating advanced scanner capabilities. Radiographers in both regions prioritised advanced imaging capabilities, for example dual-energy CT and perfusion imaging, over features including rapid scanning speed, ease of maintenance and support, and even over radiation reduction capabilities in SSA. Its prioritisation over the ease of maintenance and technical support in SSA emphasises the dedication with which radiographers in the region wish to keep pace with technological advancements and offer the most accurate and detailed diagnoses to their patients. Respondents in Ireland ranked advanced imaging capabilities after image quality and radiation reduction capabilities, again showing their dedication in keeping pace with technological advancements and offering their patients an optimal service. This could be a more achievable short-term goal in Ireland, where scanner density remains a relatively lesser concern and cost effectiveness a relatively lower priority than in SSA.

Radiographers in both regions ranked image quality among the most important features, which was expected considering the fundamental goal of radiography is to produce high quality images of the internal structures of the human body. However, the second half of this goal is to achieve detailed images with minimal radiation exposure to the patient, keeping radiation doses as low as reasonably achievable (Mahmoudi *et al.*, 2019). Those in SSA surprisingly did not rank radiation reduction capabilities as highly as in Ireland, perhaps owing to a preoccupation with more immediate concerns. Neither respondents in Ireland nor in SSA prioritised teleradiology and remote system operation over the other listed items. This was somewhat surprising for SSA where radiographers are commonly expected to report on scan findings without a radiologist present. However, radiographers in this region may be more focused on improving aspects within their official roles and responsibilities rather than improving that outside of their traditional role. Radiographers may be more interested in image interpretation assistance, previously showing strong support for AI-enabled image interpretation of common regional conditions (Botwe et al., 2020).

5.1.7. Common Manufacturer Preferences

Respondents in both regions praised CT systems manufactured by Siemens Healthineers AG., some criticising equipment manufactured by other leading manufacturers. However, respondents using CT systems manufactured by any of the five mentioned manufacturers reported generally positive usability experiences. This indicates that while brand preferences exist, their overall impact on the ability to perform required tasks may be negligible. Respondents working across multiple sites, with equipment manufactured by several different manufacturers, also reported high levels of confidence, further emphasising the general usability of scanners by the leading manufacturers. Respondents who praised Siemens Healthineers AG also reported issues, though these were mostly related to hardware elements, several respondents praising their intuitive user interface.

Most respondents reporting software issues were using CT systems not manufactured by Siemens Healthineers AG., complaining of their confusing user interface(s) and time-consuming clicking processes. This suggests that although the required tasks can be completed using scanners by any leading manufacturer, the time taken to complete these tasks may vary depending on the equipment used. This could have a considerable impact on workflow efficiency and CT scan availability and perhaps an observational study could provide valuable insights into the time lost through user-device interaction across varied CT system manufacturers. This could significantly influence brand preferences as time lost in emergency situations could be detrimental to patient outcomes (Driban et al., 2023).

5.2. Key Differences

Responses from the examined regions diverge in many instances, while their overall satisfaction with existing CT systems is clear. Their key differences relate to CT access barriers, associated issues, and their preference for specific scanner features.

5.2.1. Divergent Demographic Factors

Most respondents in Ireland were female while the majority of respondents in SSA were male. This might reflect societal differences, for example in Ghana, a lack of female access to education remains a pressing concern (Forsgren *et al.*, 2019). However, the overall research achieved a balanced representation of males and females, though with minimal response from non-binary and other gender identities. Regardless, the research does not expect significant differences in CT system usability between genders and therefore, this was not a major consideration. Another notable demographic difference between the examined populations was the increased ability to obtain higher education in Ireland than in SSA, respondents in SSA reporting a post graduate diploma at the highest level, while several participants in Ireland held a master's degree in CT. Again, this might reflect lacking educational access and a larger issue that would require governmental support and attention, were radiographers in the region unhappy with their current educational opportunities. There was a significant improvement in confidence with education (p-value=0.0006, Table 5, Appendix B), though all respondents who had received formal education in CT declared themselves confident or very confident.

5.2.2. Divergent CT Scanner Abundance

The majority of healthcare facilities in SSA reported just one CT scanner, while a large proportion of healthcare facilities in Ireland had one, two, or three CT scanners. This reflects the diagnostic divide as previously described, placing patients in SSA at risk of receiving poorer quality healthcare on account of their diminished access to crucial CT imaging. This disparity is likely more severe than it appears, with consideration for the likely far greater population to which each healthcare facility in SSA serves, when compared to those in Ireland. This again highlights the need to increase CT scanner abundance in SSA, perhaps through frugal innovation, a concept borne from resource scarcity and affordability (Chakravarty, 2022). This concept is described in the following subsections.

5.2.3. Divergent Access Barriers

Respondents in SSA perceived high cost to patients as their most significant barrier, followed by high scanner purchasing price for healthcare facilities, insufficient maintenance and technical support, and infrastructural challenges such as electrical or internet supply issues. Contrastingly, radiographers in Ireland were least concerned with infrastructural challenges, several respondents ranking this their least significant barrier compared with other items. This was not surprising and aligned with findings from the secondary research (Ngoya *et al.*, 2016; Botwe *et al.*, 2020). Perhaps increased scanner abundance could be achieved through frugal innovation, in which the complexity of CT scanners is reduced to improve cost effectiveness and accommodate simpler and quicker maintenance (Chakravarty, 2022).

5.2.4. Divergent Issue Frequency

Radiographers in Ireland and SSA selected the same four issues as their most frequently occurring, in different orders. Radiographers in SSA ranked environmental issues their most frequent issue, followed by patient condition causing scan failure, hardware issues, and software issues. Radiographers in Ireland ranked hardware issues as most frequent, followed by software issues, patient condition causing scan failure, and environmental issues. While these issues were concerning to both populations, their relative rankings suggest diverging contexts and subsequent prioritisation. For example, many respondents in SSA commented on both hardware and software issues in the comment section, while their ranking of environmental issues was more significant. This suggests that although hardware and software issues are somewhat common in SSA, they may not be as pressing as their environmental challenges. Similarly, respondents in Ireland ranked long waiting lists as their most significant access barrier by a large margin, followed by a shortage of trained professionals and limited training opportunities for radiographers. This suggests radiographers in Ireland are focused on workforce and training related barriers and may have selected some of the other barriers simply to fulfil the requirements of the questionnaire, while those in SSA are concerned with the more immediate financial and infrastructural concerns.

5.2.5. Divergent Feature Prioritisation

Similarly, several differences were observed in participants' preferences for CT system features across each region, including the aforementioned discrepancy in ranking radiation reduction capabilities. In Ireland, image quality and radiation reduction capabilities were ranked highly by a large margin, followed by user friendly operation. However, in SSA, user friendly operation received the second lowest ranking in perceived importance, after teleradiology and remote operation, with more respondents ranking user friendly operation the least important feature than any other option. This suggests that radiographers in SSA were more concerned with factors outside their own ease, placing greater importance on patient comfort, patient communication, and rapid scanning speed. This points toward a more patient-centric approach in SSA compared to the more technical approach seen in Ireland. This could be driven by resource constraints in SSA, as radiographers attempt to optimise patient outcomes within the limited available infrastructure, as those in Ireland might take patient comfort for granted and can afford to focus on other factors such as enhanced diagnostic accuracy. However, features including patient comfort and rapid scanning speed ranked similarly in SSA to radiation reduction capabilities, which could indicate a lack of appreciation for radiation reduction in the region. This may suggest a need to promote radiation safety awareness and improve radiation safety practice in SSA, further emphasised by their lacking requirement for educational harmonisation, and continued professional development (Ng'andwe and Bwanga, 2022).

Respondents' prioritisation of cost effectiveness also varied significantly between regions, with more respondents in SSA ranking cost effectiveness as the most important CT system feature than any other item. Contrastingly, no respondents in Ireland ranked this most important, again highlighting the importance of maintaining cost effectiveness in SSA compared with in Ireland, where radiographers can focus on enhancing technical performance. This further supports the argument to embrace frugal innovation in the SSA region.

5.2.6. Potential Impact of Frugal Innovation

Frugal innovation describes developing less complex medical devices in response to the high proportion of medical devices imported from the developed world to developing countries, that were soon to become dysfunctional (Chakravarty, 2022). Applying this concept to simplify CT scanners for developing countries could render cost reductions as design is focused on core functionalities and optimal performance rather than novel innovations and advanced technologies (Chakravarty, 2022). This has been successfully applied to other medical devices and services including prosthetics, cataract surgeries and even heart surgeries, indicating the positive potential to apply this concept to CT systems (Chakravarty, 2022). This has been suggested by Ogbole (2022) with regard to increasing MRI scanner abundance in Africa.

Increased scanner abundance in SSA could help meet the needs of radiographers and patients through several means. As medical equipment expenses are less, healthcare facilities may be able to charge less for CT scans, making these essential services more accessible to those with and without health insurance, reducing the impact of this access barrier. In addition, increased scanner abundance could improve workflow efficiency and expedite diagnoses by making CT scans more readily available. This would also require increased radiographer abundance, which remains an established issue in Ireland and in SSA. However, perhaps increased resource availability would improve working conditions for radiographers and encourage them to stay in their home countries rather than seeking better opportunities abroad. This could reduce the effects of brain drain, specifically with regard to service engineers.

Less complex CT scanners would require less complex and less frequent maintenance, a factor which could reduce scanner downtimes while awaiting repairs. This could have a significant impact on patients in SSA, where delays to receive crucial medical imaging have been directly linked with increased mortality rates (Driban *et al.*, 2023; Pongweni, 2024). Reducing the length of scanner downtimes could be particularly useful where healthcare facilities have just one CT scanner and are without auxiliary support for emergency cases. This presents another argument for frugal innovation, if even only as a temporary measure. Song (2024), speaking on medical devices as a whole, suggests the production of less complex devices along with an urgent call by WHO for government organisations and private corporations to support the more long-term solutions, such as investing in infrastructural enhancement. Similarly, the present study asserts that urgent action is needed to address the diagnostic divide, whether through short or long-term solutions, as patients in developing countries continue to endure sub-standard healthcare.

5.3. Summary

In summary, both cohorts appeared satisfied with their overall CT system usability and were primarily concerned with improving access to CT imaging in their respective countries. Radiographers in Ireland were more concerned with workforce and training related barriers, while radiographers in SSA were more concerned with financial and infrastructural challenges. Both cohorts reported on issues with hardware and software, though their overall experiences remained positive. Both cohorts also expressed a strong interest in advanced imaging technologies, demonstrating their common commitment to improving diagnostic accuracy. Neither cohort was majorly concerned with regulatory issues or teleradiology and remote operation, relative to the other listed items.

5.4. Common Recommendations

Some common recommendations can be made to improve the overall usability and accessibility of CT imaging services.

- Improve the durability of the CT scan table to reduce the frequency of scanner downtimes and improve workflow efficiency.
    - SSA and reduce the overall impact of scanner downtimes on healthcare facilities as they await maintenance.
    - This could help reduce the frequency of scanner downtimes in Ireland, helping to reduce the length of waiting lists for CT scans.
- Increase the CT scan table weight limit to keep pace with rising global obesity (McCárthaigh, 2021; Martey *et al.*, 2024).
    - This could address the existing table weight limitations in Ireland, with one of the highest obesity rates in the EU (McCárthaigh, 2021).
    - This could help prepare radiology departments across SSA for their rising obesity levels (Martey *et al.*, 2024).
    - This could help reduce time lost trying to accommodate larger patients and improve workflow efficiency while aiding patient dignity and comfort.
- Improve the CT scanner gantry bore limits to increase access to CT and improve workflow efficiency.
    - This could also reduce time lost to patient positioning challenges where the patient does not fit easily within the scanner gantry. These issues can occur even where patients do not exceed weight limits, for example with severe spinal kyphosis.
    - Enabling a wider range of patients to be positioned within the scanner isocentre could also improve the accuracy of radiation doses delivered, as positioning outside the isocentre has been shown to deliver inappropriate radiation doses (Dane *et al.*, 2021).
- Remove confusion from the CT system user interface(s) to enhance the user experience and improve workflow efficiency.
    - This is a long-term recommendation given the overall satisfaction with existing system user interface(s) expressed by the respondents.

    - Improving the ease with which radiographers navigate the user interface in a time pressured environment can increase accuracy, workflow efficiency and the radiographer's overall experience.
    - Radiographers in both regions praised the user interface developed by Siemens Healthineers AG. which could serve as a gold-standard for prospective designs.
- In the longer term, manufacturers could explore the less common suggestions, including the integration of more paediatric CT imaging protocols to increase efficiency when dealing with paediatric patients.

5.5. Recommendations for Ireland

Some recommendations can be provided to improve the usability and accessibility of CT imaging services in Ireland.

- Attention must be given to radiography staffing challenges and the impact of the recent hiring freeze on radiographers in Ireland.
    - Since the beginning of this research, the hiring embargo on the national public health service in Ireland has ended. However, experts warn this has been replaced with a staff ceiling and that the chronic staffing issues may not be adequately addressed even in its absence (RTE, 2024).
    - CT system design alterations cannot replace adequate staffing, however, increasing workflow efficiency and improving ease of use may help to alleviate some of the strain on radiographers.
    - This could also help address the long waiting lists for CT scans in Ireland with design changes aimed at improving workflow efficiency serving as a supplementary measure.
    - Improving training opportunities for radiographers in Ireland could also help to alleviate staff shortages.
- Efforts should be made to enhance CT scanner patient monitoring systems.
    - This was expressed by several radiographers and could help to enhance patient safety, especially during and immediately following the scan.

5.6. Recommendations for SSA

Some recommendations can also be made to improve the usability and accessibility of CT imaging services in Sub-Saharan Africa.

- Embrace frugal innovation to address financial, maintenance, and infrastructural challenges in SSA.
    - Reducing the costs associated with CT imaging systems, from scanner purchasing price to the cost to patients, could help to increase CT scanner abundance. This could have a significant impact on access to CT imaging services in the region, and on the provision of healthcare in general.
    - Less complex CT scanners would require less complex and less frequent maintenance procedures, helping to resolve the gross shortage of service engineers and biomedical professionals in the region.
    - Less complex scanners would also demand less from infrastructural resources, due to the relatively basic operational performance. This could reduce the incidence of infrastructural issues on imaging facilities in SSA, improve their workflow efficiency and increase overall access to CT.
- Train radiographers to perform basic scanner maintenance to address the shortage of service engineers across Africa.
    - Radiographers could be trained to perform basic maintenance tasks such as cleaning internal components to remove dust or replacing used cathode filaments to address common causes of scanner failure, increasing scanner uptime (Mathur, 2022).
    - This could also be implemented in Ireland to help reduce downtimes and decrease waiting lists. However, reported downtimes are not as significant in Ireland and thus, such extreme measures are unlikely to be taken.
    - Such role expansion would require great consideration before official role changes were made. This would require a nuanced and cautious approach with consideration for the protection of the service engineer's practice, while safeguarding the radiographer's liability. Given the complexities involved, this expansion may be more achievable in the long term, though should be considered as the reported shortage of service engineers is not expected to be resolved in the short term.
- Policy changes to reduce the divide between private and public services in the region.

    - Reducing the dominance of private imaging services across SSA could address access issues by reducing the distance between accessible services for those without health insurance.
    - Some studies have suggested public-private partnerships could assist in reducing healthcare inequities by reducing the divide between the two service types (Kabongo *et al.*, 2015; Srivarathan *et al.*, 2024).
- Increase radiation awareness and prioritisation.
    - Radiation reduction capabilities ranked lower than anticipated in the CT system features section.
- In the longer term, manufacturers could address less common suggestions such as the integration of local languages into CT systems to improve communication and improving the visibility of the projected dose before scanning.
    - There are over 1,000 languages spoken across Sub-Saharan Africa, with over 2,000 languages spoken on the African continent (Royal Berglee, 2016). Radiographers often rely on CT scanners to deliver pre-recorded audio instructions to patients during scanning, for example specific breathing instructions, where the radiographer and patient do not speak the same language (Choong *et al.*, 2021).
    - Making the projected dose reading more visible to radiographers before initiating their scan could help to avoid radiation incidents, a concern previously raised.
    - Manufacturers should integrate advanced imaging capabilities to ensure the needs of radiographers in SSA are met. However, this may not be feasible in the short-term while efforts to enhance CT imaging are focused on increasing scanner abundance.

5.7. Study Limitations

There were a number of limitations associated with this study, the most prevalent being a failure to meet the required sample size. The required sample size was 148, while the achieved sample size was 52. This leaves the data open to data fluctuations which could ultimately impact the generalisability of the findings to a broader population. The relatively small sample also increases the risk of bias thus the findings of this study should be regarded as indicative rather than definitive (Faber and Fonseca, 2014).

5.7.1. Sample Size

Several potential reasons for the relatively small sample achieved can be conceived, for example, the generally low response rates associated with healthcare workers due to obvious time constraints (Ellis *et al.*, 2022). The present research questionnaire took on average 18 minutes to complete, which many radiographers may not have been able to spare. The research also offered no incentive and took place during the summer months in Ireland during which time radiographers may not wish to discuss work-related activities (Ellis et al., 2022). Furthermore, burnout remains a commonly reported sentiment in the radiography profession which may also have contributed to participants' reluctance to partake in the research (Reingold, 2015; Singh *et al.*, 2017; Foley *et al.*, 2020; Sipos *et al.*, 2024). Survey fatigue is also commonly reported and may have been a contributing factor due to the many research studies carried out following the Covid-19 pandemic (Foley et al., 2020; Lewis and Mulla, 2021; Lewis, 2023). In SSA, political unrest may also have affected participants' willingness to partake in the research, perhaps on account of emotional strain and a focus on more immediate concerns (Mhaka, 2024). The researcher also had no personal contacts in SSA, and participant recruitment was reliant on the traditional recruitment methods such as e-mail and social media.

The sample size calculation also proved particularly challenging as no data was found which stratified radiographers by the imaging modality in which they worked e.g., CT, MRI, US, nuclear medicine. This meant the sample size calculation was based upon estimates and may have been underestimated or overestimated with a greater likelihood that there are fewer radiographers working in CT than estimated, as based upon the researcher's background working as a CT radiographer.

5.7.2. Interpretation of Findings

This study examined CT system accessibility and usability specific to Ireland and Sub-Saharan Africa. Thus, the research findings should not be applied to other regions without consideration for their own unique demographic and contextual factors.

In addition, healthcare facilities in Ireland often have a greater abundance of CT scanners than those in SSA and therefore, while they may have commonalities, the impact of some factors on each region may significantly differ.

The research also included a self-report question around user confidence which may have introduced bias as participants may have wished to appear favourably despite remaining anonymous (Nikolopoulou, 2022).

5.8. Research Implications

If embraced, the findings from this research could positively impact access to CT imaging services.

- Increases awareness of the diagnostic divide through direct comparison of critical needs and barriers related to CT imaging in developed and developing regions.
- Contributes to the limited research on the radiography profession, with particular focus on CT radiographers.
- Provides direct recommendations to manufacturers and policymakers to enhance the provision of CT imaging services in the examined regions.
- Highlights the detrimental effects reduced imaging access can have on patient outcomes and the provision of quality care.
- Provides a framework for future research to compare user needs between distinct cohorts.
- Recommends research studies that could add to the discourse on healthcare inequities, user needs assessments, and the radiography profession.

5.9. Recommendations for Research

The present research offers several suggestions for future studies to contribute to the relevant discourse.

- The results of this study could be validated by conducting an in-depth interview study or extending the response period for the questionnaire to ensure a sufficient sample size is reached.
- A derivative study could apply a similar framework to evaluate radiographers' experiences in different countries, or across other imaging techniques e.g., US, nuclear medicine. This could validate or disprove the need to customise medical device design to meet the specific needs of radiographers in varied contexts.
- An observational study could offer interesting and valuable insights into the time lost through user-device interactions with CT scanners produced by different CT system manufacturers. Alternatively, this could be performed for another medical imaging device or medical device category.

- The research strongly suggests an audit is carried out to ascertain the respective distribution of radiographers across different imaging modalities e.g., CT, MRI, US, nuclear medicine and so on. This would help future researchers to more accurately determine an accurate sample size requirement for similar studies, increasing the potential validity of their study.

Chapter 6: Conclusion

In conclusion, the present research identified several commonalities and differences between CT radiographer experiences in Ireland and in Sub-Saharan Africa. Radiographers in both regions expressed an overall satisfaction with existing CT systems, identifying several areas for improvement which were ultimately deemed low-priority relative to their more critical needs and concerns.

Many of the research findings aligned with existing literature such as the prevailing financial and infrastructural challenges throughout Sub-Saharan Africa, and the apparent radiographer shortages in both regions. In addition, radiographers' evident frustration with limitations on scan table weight and gantry bore size were unsurprising given the breadth of research surrounding this topic. Some readers, however, may not have anticipated these limitations to apply to developing countries, as depicted in this research. Radiographers in Sub-Saharan Africa appeared more concerned with the shortage of biomedical professionals in the region than the shortage of radiographers, claiming they were often unable to quickly resolve CT scanner breakdowns. Also somewhat unexpected, radiographers in Sub-Saharan Africa were relatively disinterested in teleradiology and remote operation facilities. This was surprising given the abundance of reports on radiologist shortages and the increased expectation of radiographers to report on scan findings. However, radiographers in Ireland were also disinterested in these features, meaning efforts to integrate teleradiology or remote operation into CT systems may be ineffectual in enhancing the radiographers' experience at this time.

Another unanticipated finding was the apparent absence of refurbished CT systems in Sub-Saharan Africa relative to prevailing research. This is thus unlikely to contribute to the CT access issues in the region, contrary to common belief. The more likely contributors to their access issues are related to financial and infrastructural shortcomings, insufficient scanner maintenance, and their relative CT scanner scarcity. Radiographers in Sub-Saharan Africa expressed most concern for the high cost of acquiring CT scanners, and the costs incurred by patients. Such issues may be worsened by the apparent privatisation of CT imaging in the region, with most respondents in Sub-Saharan Africa working in private healthcare facilities whereas in Ireland, most worked in the public sector. Both regions were impacted by the urbanisation of CT imaging services, patients in rural areas forced to travel long distances to access these services, again aligning with existing literature.

Somewhat unsurprisingly, radiographers in Ireland were most concerned with workforce and training-related issues, while those in SSA remained focused on financial and infrastructural issues. Reports from radiographers in Sub-Saharan Africa suggest that they too face many of the same challenges as radiographers in Ireland. However, the perceived importance of these challenges may appear less as radiographers in this region are focused on the more pressing and immediate issues. This informs the argument to reduce the complexity and cost associated with CT scanners, perhaps through frugal innovation, to increase their scanner abundance and thus increase access to crucial imaging services, with immediate effect. Such reduced complexity could also help to achieve more basic and less frequent maintenance procedures to address chronic service engineer shortages, with an additional recommendation to train radiographers in simple maintenance tasks. Less immediate strategies to enhance CT imaging services in Sub-Saharan Africa include increased radiation safety awareness in the region and the integration of local languages. Strategies to enhance access to CT imaging services in Ireland include policy revisions to address radiography staffing challenges, and specific CT system enhancements such as advanced patient monitoring systems.

To conclude, the diagnostic divide between CT imaging services in Ireland and Sub-Saharan Africa is evident, and region-specific strategies must be urgently implemented to enhance these services both in Ireland and in Sub-Saharan Africa. These strategies are instrumental in improving patient care in both regions, and ensuring progress is made toward achieving equitable health outcomes. Such strategies should focus on addressing the most critical needs and priorities of radiographers in each region, rather than focusing on the relatively less significant usability challenges.

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Appendix A – CT Radiographer Population Estimates

Country	*Total population (in millions)*	*Radiographer population*	*Estimated CT-trained radiographer population*	*Estimated ratio of CT-trained radiographers to total population*	*Reference*
Ghana	34.7	300	138	0.000004	(Wuni *et al.*, 2020; Worldometer, 2024)
Lesotho	2.3	n/a	n/a	n/a	(Worldometer, 2024)
Nigeria	228.7	2,000	920	0.000004	(Ikechukwu *et al.*, 2023; Worldometer, 2024)
Rwanda	14.4	118	54	0.0000038	(Rosman *et al.*, 2015; Worldometer, 2024)
South Africa	61	7910	3639	0.00006	(Kawooya *et al.*, 2022; Worldometer, 2024)
Zimbabwe	17	386	178	0.00001	(Worldometer, 2024)
Total (SSA)	358.1	10,714	5,730	0.000082	
Average (SSA)				0.000016	
Total (Ireland)	5.1	3,198	1471	0.00029	
Combined Total			7,201		

Table 2: Estimation of CT-trained Radiographer Population

Appendix B – Statistics Calculation Tables

Experience vs. Confidence (Observed)				
	Somewhat confident	Confident*	Very confident*	p-value
0-1 years	2	0	0	
1-5 years	2	15	6	
5-10 years	0	5	7	
10+ years	0	1	14	
Experience vs. Confidence (Expected)				
	Somewhat confident	Confident*	Very confident*	
0-1 years	0.1538	0.808	1.038	
1-5 years	1.7692	9.288	11.942	
5-10 years	0.9231	4.846	6.231	
10+ years	1.1538	6.058	7.788	
				1.95801E-07

Table 3: Experience vs. Confidence (Overall) Chi-Square Test

Gender distribution (Observed)			
	SSA	Ireland	Total
Male	12	7	19
Female	8	23	31
Other	1	1	2
Total	21	31	52
Gender distribution (Expected)			
	SSA	Ireland	Total
Male	7.67	11.33	19
Female	12.52	18.48	31
Other	0.81	1.19	2
Total	21	31	52
Chi-Square Values			
	SSA	Ireland	Total
Male	2.4	1.62	
Female	1.62	1.1	
Other	0.04	0.03	
Total			6.81
Degrees of Freedom	2		
p-value	0.033		

Table 4: Gender Distribution (SSA vs. Ireland) Chi-Square Test

Education vs. Confidence (Observed)					
	Somewhat confident	Confident*	Very confident *	Total	p-value
Bachelor's degree in Radiography, excl. CT education	4	1	6	11	
Bachelor's degree in Radiography, incl. CT education	0	16	8	24	
Master's degree specific to CT	0	1	5	6	
Post-graduate degree specific to CT	0	3	6	9	
Post-graduate certificate in CT	0	0	2	2	
Total	4	21	27		
Education vs. Confidence (Expected)					
	Somewhat confident	Confident*	Very confident *		
Bachelor's degree in Radiography, excl. CT education	0.85	4.44	5.71	11	
Bachelor's degree in Radiography, incl. CT education	1.85	9.69	12.46	24	
Master's degree specific to CT	0.46	2.42	3.12	6	
Post-graduate degree specific to CT	0.69	3.63	4.68	9	
Post-graduate certificate in CT	0.15	0.81	1.04	2	
					0.000614

Table 5: Education vs. Confidence Chi-Square Test (Overall)

Appendix C – Ethics Application Form

Ethics Application & Declaration Form

DISSERTATION TITLE: Developing a Framework to Enhance Computed Tomography Access and Usability in Sub-Saharan Africa: An Evaluation of Radiographers' Needs across Developed and Developing Countries

RESEARCHER'S NAME: Jill Creedon

PROGRAMME OF STUDY: MSc Medical Device Technology and Business

SUPERVISOR'S NAME: Dr. Áine Behan

DECLARATION:

The information in this application form is accurate to the best of my knowledge. I undertake to abide by the principles outlined by Innopharma/Griffith College ethics policy in my research dissertation. I confirm that I have completed a full ethics assessment for my research dissertation as per the college guidelines. I will not begin my primary research until such approval from my supervisor and/or ethics Committee has been obtained.

I pledge to carry out my research according to the Innopharma/Griffith College academic integrity standards. Any results presented in my dissertation will be from my own, original research, I will reference and/or acknowledge any material or sources used in its preparation and I will not plagiarise the work of anyone else.

For Student:

STUDENT SIGNATURE:

DATE: 26/04/2024

The research contained within this research dissertation proposal has been approved.

For Supervisor:

Ethics Committee Approval Required: Yes ☐ No ☐

SUPERVISOR SIGNATURE:

DATE:

For Ethics Committee (if required):

Ethics Committee Approval Given: Yes ☐ No ☐

ETHICS COMMITTEE MEMBER SIGNATURE:

DATE:

NOTE: Supervisors are responsible for ensuring their students fill in this form correctly and that all ethical areas have been considered.

SECTION 1: DESCRIPTION OF RESEARCH STUDY

1.1 Purpose and objectives of research *[300 words maximum/ use literature review findings to guide]*

The proposed research aims to perform a comparative user needs assessment between radiographers in Ireland and radiographers in the English-speaking countries of Sub-Saharan Africa, with respect to computed tomography (CT) system use. The research intends to use the collected information to establish a framework for CT system manufacturers to make appropriate CT system design changes to reflect the needs of radiographers in Ireland and the English-speaking countries of Sub-Saharan Africa. The aim is to encourage manufacturers to consider the diversity of user need across developed and developing countries, in particular. The proposed research focuses on Sub-Saharan Africa, where a shortage of medical imaging services has been linked with increased morbidity and mortality (Driban *et al.*, 2023). The proposed research was conceptualised following publication of several reports citing a historical exclusion of minority ethnic groups from the medical device design process (Davis, 2024; Johnson and Ensor, 2024). The secondary research identified a chronic shortage of medical imaging equipment across Sub-Saharan Africa that is yet to have been met with a sustainable solution (Global Health, 2023). Some studies have suggested altered CT system design to enhance CT imaging access, though no research appeared to address the specific needs of CT radiographers in Sub-Saharan Africa. The proposed research seeks to provide user insights across developed (Ireland) and developing (Sub-Saharan Africa) regions to enable CT system manufacturers to devise a more sustainable solution to the CT imaging access issues present throughout the developing world. The research should identify existing obstacles, opportunities, strengths, and challenges with CT system usability with an aim to enable CT system manufacturers to enhance prevailing CT system design.

Objectives:

1. To identify the needs of CT radiographers across Ireland and the English-speaking countries of Sub-Saharan Africa
2. To identify obstacles, opportunities, strengths, and challenges to CT system use and accessibility across Ireland and the English-speaking countries of Sub-Saharan Africa
3. To propose recommendations to enhance CT system usability and accessibility across Ireland and the English-speaking countries of Sub-Saharan Africa

Research methodology: [*300 words maximum/ detail how you will acquire your primary data (focus groups/interviews/online surveys etc). Proposed questions for questionnaires and/or interviews **must be included** in the appendix*].

The research used a semi-structured online survey questionnaire to obtain the perspectives and opinions of CT radiographers across Ireland and the English-speaking countries of Sub-Saharan Africa regarding CT system usability and accessibility. Online questionnaires were most appropriate due to their quicker and higher response rates when compared with traditional means, important for ensuring perspectives were gathered from a diverse population. Online questionnaires also allowed dissemination across diverse geographical locations, while also removing interviewer bias. Online questionnaires also encouraged anonymity, which may have enhanced the honesty of responses received (Ong and Weiss, 2000). While interviews are typically associated with greater depth in response, valuable interview data relies heavily on maintaining a stable internet connection which may have proved challenging in parts of SubSaharan Africa and rural Ireland (Codó, 2009). The questionnaire was developed using MS forms and contained several closed question modes to achieve maximum data value, specifically: MCQ (dichotomous), MCQ (standard), Likert-style and ranking scale style questions. These questions would allow direct comparison between answers obtained from Ireland and Sub-Saharan Africa. Open qualitative questions were used to gather contextual information to support quantitative data, though qualitative questions remained optional to enhance the participant experience. All responses were anonymous, and no sensitive data was obtained. The questionnaire contained a short summary before obtaining informed consent to participate in the study. The summary contained information on the research purpose, objectives, methodology, data collection practices and predicted data retention period. Once informed consent was obtained, participants were asked to qualify their English language proficiency. The remaining questions were split across four categories, namely: demographics, critical needs and priorities, contextual factors, and usability. Participants were invited to additional comments and/or feedback before closing the questionnaire.

SECTION 2: POSSIBLE ETHICAL ISSUES

Answer 'yes' or 'no' to the following questions.

SUBJECT MATTER

Does the research proposal involve:

Research into specific company activities that would be deemed sensitive or confidential

Yes No✓

Research into politically and/or racially/ethnically and/or commercially sensitive areas

Yes No✓

Sensitive, personal, professional, or corporate issues

Yes No✓

RESEARCH PROCEDURES

Does the research proposal involve:

Research that might damage the reputation of companies or participants

Yes No✓

Research that may negatively affect the reputation of Griffith College/Innopharma

Yes No✓

Use of personal records without consent

Yes No✓

Use of company data without consent

Yes No✓

The offer of any inducements to participate

Yes No✓

Audio or visual recording without consent

Yes No✓

Using a language other than English

Yes No✓

PARTICIPANTS

Does the research proposal involve:

People who are not competent and/or fluent in English

Yes No✓

Does your research group include any of the following vulnerable groups

Yes No✓

(Adults with psychological impairments; Adults with learning difficulties; Adults under the protection/control /influence of others (e.g. in care/prison); Relatives of ill people (e.g. parents of sick children); Hospital or GP participants recruited in a medical facility; persons under the age of 18)

If you have answered NO to ALL questions, please go straight to Section 4.

If you have answered YES to ANY question in SECTION 2, you must fill in SECTION 3.

SECTION 3: STEPS TAKEN TO AVOID ETHICAL ISSUES

[Only fill in this section if you answered YES to ANY of the questions in Section 3. For example, if you answered yes to including participants who are not fluent in English, you might put forward a plan that offers your survey in two languages to take this into account. Another example could be a study where the researcher wants to include information about the care received by children with a long-term condition but it would not be ethical to approach the children directly but it might be acceptable to instead ask parents questions about their child's care. If these plans are acceptable to your supervisor, you may not need to apply for ethical approval from the Ethics Committee].

3.1. If your ethics relates to ***Subject Matter***, outline your action plan to work around any sensitive issues.

3.2. If your ethics relates to ***Research Procedures***, outline your action plan to deal with possible ethical issues in your research procedures.

3.3. If your ethics relates to ***Participants***, outline how you will protect vulnerable persons or those that do not have English as their first language.

SECTION 4: ABOUT YOUR PARTICIPANTS

4.1. Outline your participant profile and why you have chosen them for this study *[Do not provide names except where it is deemed impossible to conceal identity].*

The research will recruit CT radiographers who are currently practicing in Ireland or the Englishspeaking countries of Sub-Saharan Africa. Participants must have some level of CT experience, and those with no experience with CT systems will not participate in the survey questionnaire. Participants must be proficient in the English language, as assessed through a qualifying question at the beginning of the survey questionnaire. Those who are not proficient in the English language will not participate in the survey questionnaire. The questionnaire will be distributed throughout Ireland and the Sub-Saharan African countries in which English is a listed, official language. Participants who fit this profile are most appropriate for the survey questionnaire and their responses would be collected.

4.2 How do you plan to gain access to/contact/approach your participant(s)?

The researcher aims to approach participants through various channels, using social media platforms including Facebook, WhatsApp, and LinkedIn. The researcher also plans to contact radiology services managers, using their publicly available e-mail addresses, to request internal questionnaire dissemination across their respective sites. The researcher should also recruit participants through contact with various professional bodies such as the Irish Institute of Radiography and Radiation Therapy (IIRRT), the Society of Radiographers of South Africa (SORSA) and the Society of Radiography in Kenya (SORK).

SECTION 5: INFORMATION, CONSENT AND CONFIDENTIALITY

5.1 Participant Information Letter (PIL) for participants

[You must submit an information letter for participants with this application, as part of your appendices document. For online surveys, it is sufficient to include a paragraph summarising and explaining the purpose of the research at the beginning of the survey. In all other research e.g. interviews, phonecalls, a PIL should be provided to each participant before they are asked for their consent to take part. A template PIL is available in Moodle].

N/A

Please confirm below that your information letter covers:

Description of the research topic and method

Yes No

Details of what participation will involve

Yes No

Rights to anonymity

Yes No

Confidentiality

Yes No

Rights to withdraw from the research

Yes No

The contact details of the researcher and supervisor (if necessary)

Yes No

5.2 Informed Consent Form (ICF) for participants

[Informed consent is required for most research. For online surveys, it is sufficient to get the participant to tick two boxes at the beginning of the survey – one to state they understand

the research and one to give consent. In all other research e.g. interviews, phonecalls, a signed consent form is required. If the data is gathered online e.g. zoom, a signed consent form can be scanned and sent to the researcher. A template ICF is available in Moodle. The signed ICFs, along with the surveys, audio files or interview notes etc. must be stored in the primary data folder on moodle and can be accessed by Innopharma staff for the purposes of verifying the authenticity of the research carried out and the data collected].

Please indicate below if your research requires a signed consent form by selecting the relevant option only:

Yes: my research requires signed consent and I have attached an ICF in the appendices of my application

No: my research study involves an online survey only and/or does not require signed consent ✓

SECTION 6: STORAGE OF DATA

[Please ensure that you are abiding by GDPR and the national Data protection laws https://www.hrb.ie/funding/gdpr-guidance-for-researchers/gdpr-and-health-research/).

*The student is responsible for storage of data and this will be handed over to the college in an electronic format as part of the thesis submission i.e. primary data and completed ICFs where applicable will be added to the primary data folder on moodle. The rationale is to keep data **as long as it is still useful** and there is an intention to use it further **for research** so if this is not the case then this can be stipulated here and a shorter retention period given.]*

6.1. How will you store the research data and for how long? How will you manage data protection issues?

Data relevant to the proposed research will be collected. No sensitive or identifying data will be obtained. Obtained data will be stored on a password-protected laptop, accessible only to the researcher. When the laptop is not in use, it will be stored in a locked room, accessible again only to the researcher. Raw data will be shared only with the relevant supervisor. Obtained data should be retained for a maximum period of 4 years following awarding of the MSc qualification.

SECTION 7: NON-DISCLOSURE AGREEMENT & STUDENT CONSENT

7.1 Non-Disclosure Agreement (NDA)

Will the final dissertation contain any information pertaining to any source what would warrant the use of a Non-Disclosure Agreement (NDA) e.g. industry-based research?

Yes No✓

7.2 Student consent

If a Non-Disclosure Agreement (NDA) is not required, does the Student consent to allow their completed dissertation to be held/published by Innopharma/Griffith College?

Yes✓ No

SECTION 8: RECORDING AND RETENTION OF DISSERTATION VIVA

8.1 Viva Recording

The Dissertation viva will be recorded. This recording may be used to facilitate assessment by Innopharma staff, a third reader if necessary and/or if requested by the external examiner for the Programme. The recording will be held in line with current GDPR guidelines and will not be made publicly available.

SECTION 9: DOCUMENT CHECKLIST

NOTE: Applicants must attach the following documents in electronic format to the appendix.

Which documents are added to the appendix? Please tick N/A if not applicable:

9.1 Participant Information Letter (PIL) for participant

Yes N/A✓

9.2 Informed Consent Form (ICF) for participant

Yes N/A✓

9.3 Questions/survey for interviewees/focus groups etc *(can be in draft form)*

Yes✓ N/A

9.4 Any other documents e.g. Non-Disclosure Agreement

Yes N/A✓

I confirm that this application is complete and all required documents are included in the appendix.

For Student :

STUDENT SIGNATURE:

DATE: 26/04/2024

Appendix D – Questionnaire

Enhancing the CT Scanning Experience: Radiographers' Insights

This questionnaire seeks to capture your experiences with CT system operation, exploring topics such as CT scanner operation, workflow efficiency, patient communication and technical performance. The questionnaire should take approximately 10-20 minutes to complete, depending on your depth of response.

Your feedback will help us identify opportunities to modify CT system design, encouraging manufacturers to listen and respond to your needs. The research will also compare the needs of CT radiographers in developed and developing countries to determine whether region-specific modifications could help to enhance access to essential CT imaging services in areas where access is limited.

All responses will remain anonymous and any obtained data will be used for research purposes only. Your participation is voluntary and you may withdraw from the study at any time. Thank you in advance for your valuable insights!

* Required

1. By ticking the following boxes, I consent to participate in this study *

Please select 4 options.

- ☐ I am proficient in the English language
- ☐ I understand the purpose of this study
- ☐ I consent to my information being used for the purposes of this study
- ☐ I consent to participate in this study

2. How would you best describe your gender? *

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ Prefer not to say
- ◯ Other

3. What is your current profession? *

- ◯ I am a CT radiographer working in Ireland
- ◯ I am a CT radiographer working in Sub-Saharan Africa

4. What country are you currently working in? *

- ◯ Angola
- ◯ Benin
- ◯ Botswana
- ◯ Burkina Faso
- ◯ Burundi
- ◯ Cameroon
- ◯ Cape Verde
- ◯ Central African Republic
- ◯ Chad
- ◯ Comoros
- ◯ Congo (Brazzaville)
- ◯ Congo (Democratic Republic)
- ◯ Côte d'Ivoire
- ◯ Djibouti
- ◯ Equatorial Guinea
- ◯ Eritrea
- ◯ The Kingdom of Eswatini (Swaziland)
- ◯ Ethiopia
- ◯ Gabon
- ◯ The Gambia
- ◯ Ghana
- ◯ Guinea
- ◯ Guinea-Bissau
- ◯ Kenya
- ◯ Lesotho
- ◯ Liberia
- ◯ Madagascar
- ◯ The Republic of Malawi
- ◯ Mali
- ◯ Mauritania

- ◯ Mauritius
- ◯ Mozambique
- ◯ Namibia
- ◯ Niger
- ◯ Nigeria
- ◯ Rwanda
- ◯ São Tomé and Príncipe
- ◯ Senegal
- ◯ Seychelles
- ◯ Sierra Leone
- ◯ Somalia
- ◯ South Africa
- ◯ The Republic of South Sudan
- ◯ Sudan
- ◯ The United Republic of Tanzania
- ◯ Togo
- ◯ Uganda
- ◯ Zambia
- ◯ Zimbabwe
- ◯ Other

5. What type of institute do you work in? *

Select multiple options, where needed.

- ☐ Public hospital
- ☐ Private hospital
- ☐ Private clinic/out-patient centre
- ☐ Mobile radiography service
- ☐ Other

6. What type of geographical area are you working in? *

Select multiple options, where needed.

- ☐ Urban area
- ☐ Suburban area
- ☐ Rural area
- ☐ Other

7. How many scanners are available at your facility? *

- ○ 1
- ○ 2
- ○ 3
- ○ 4+
- ○ Other

8. Where did your facility obtain their CT scanners? *

Select multiple options, where needed.

- ☐ Purchased/leased from manufacturer
- ☐ Purchased/leased from third-party distributor
- ☐ Purchased/leased on the second-hand market
- ☐ Acquired from a government organisation
- ☐ Acquired from a charity organisation
- ☐ Uncertain
- ☐ Other

9. In what condition were your facility's CT scanners obtained? *

Select multiple options, where needed.

- ☐ New
- ☐ Second-hand, refurbished
- ☐ Second-hand, not refurbished
- ☐ Uncertain

10. Which CT system manufacturers have you used? *

Select multiple options, where needed.

- ☐ Siemens Healthineers AG
- ☐ GE Healthcare Technologies Inc.
- ☐ Canon Medical Systems Corp.
- ☐ Philips Healthcare
- ☐ Neusoft Medical Systems Corp Ltd.
- ☐ Other

11. What is your highest qualification <u>specific to CT imaging?</u> *

- ◯ Bachelor's degree in Radiography, <u>excluding CT education</u>
- ◯ Bachelor's degree in Radiography, <u>including CT education</u>
- ◯ Post-graduate diploma, <u>specific to CT</u>
- ◯ Master's degree <u>specific to CT</u>
- ◯ Ph.D. <u>specific to CT</u>
- ◯ Other

12. What additional CT training have you received? *

Select multiple options, where needed.

- ☐ None
- ☐ Independent online learning
- ☐ Formal classroom training sessions
- ☐ Training provided by colleagues
- ☐ Training provided by the equipment manufacturer
- ☐ Other

13. How many years have you been performing CT scans in the country you have selected? *

- ◯ 0-1 years
- ◯ 1-5 years
- ◯ 5-10 years
- ◯ 10+ years

14. How would you rate your confidence when performing CT scans? *

- ◯ Very confident
- ◯ Confident
- ◯ Somewhat confident
- ◯ Not very confident
- ◯ Not confident at all

15. Please elaborate on your response to the previous question:

Optional

16. Please rank the following barriers to CT imaging in your selected country (1 being most significant and 10 being least significant) *

Regulatory challenges
Infrastructural challenges such as unstable electrical supply or internet connection
Limited training opportunities for radiographers
Shortage of trained professionals (radiographers, radiologists, biomedical engineers, medical physicists)
Long waiting lists for CT scans
High CT scanner purchasing price (for healthcare facilities)
Negative perception of healthcare in the community
Geographical obstacles (e.g., long distance to CT imaging services)
High cost of CT scans (for patients)
Insufficient maintenance and/or technical support

17. Can you describe a specific challenge your CT department has faced regarding any of the above listed barriers?

Optional

Please read the following instruction

To help us identify specific areas for improvement, the following questions refer to either the CT system user interface or CT scanner hardware.

The CT system user interface refers to the software you might interact with when performing a CT scan e.g., the scanning monitor screen display. This section aims to examine 'ease-of-use' when navigating through on-screen features and performing on-screen tasks before, during and after performing the CT scan.

The CT scanner hardware refers to any physical components you might interact with when performing the CT scan e.g., the control panel buttons, patient table controls, scanner gantry controls. This section aims to examine 'ease-of-use' around patient positioning and communication before, during and after the CT scan.

18. Do you understand the above distinction? *

- ◯ Yes, I understand
- ◯ No, I do not understand

19. Please read the following statements and select the most appropriate response. Each statement relates to the CT system user-interface. *

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I can easily select the appropriate patient for each scan	○	○	○	○	○
There are pre-set imaging protocols to suit most of my CT scanning needs	○	○	○	○	○
I can easily navigate through the different imaging protocols to make the most appropriate selection	○	○	○	○	○
I can easily make appropriate changes to pre-set exposure parameters prior to commencing the CT scan	○	○	○	○	○
There are sufficient exposure parameter options to accommodate various imaging requirements, patient sizes, and patient presentations (e.g., tube voltage (kV), tube current (mA), rotation time (s), slice thickness (mm) etc.)	○	○	○	○	○
The projected patient dose (e.g., dose-area-product (DAP)) is clearly visible to me before I initiate the CT scan	○	○	○	○	○
Disregarding external factors such as patient movement, the images I produce are consistently diagnostic in terms of technical image quality e.g., image noise, image contrast, and spatial resolution	○	○	○	○	○
I can easily navigate the user interface to perform necessary post-processing tasks such as multi-planar reconstructions (MPRs) and/or 3D image reformats	○	○	○	○	○

I can perform multiple consecutive scans without experiencing software malfunctions such as the use interface becoming unresponsive	○	○	○	○	○
The CT system software integrates well with other platforms e.g., radiology reporting workstations, radiology information systems (RIS), hospital information systems (HIS)	○	○	○	○	○

20. Can you describe a specific challenge you have encountered with the CT system user-interface?

Please provide as much detail as possible (optional)

Enter your answer

21. Overall, I am satisfied the CT system user-interface meets my needs as a CT radiographer *

- ○ Strongly disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly agree

22. Can you describe any features that could enhance your CT scanning experience, with specific reference to the CT system user-interface?

Optional

CT system hardware:

23. Please read the following statements and select the most appropriate response. Each statement relates to the <u>CT scanner hardware.</u> *

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I can easily navigate through the control panel buttons (e.g. through in tuitive placement, clear button labelling etc.)	○	○	○	○	○
Using the appropriate controls, I can easily adjust the patient table position +/- scanner gantry angle	○	○	○	○	○
I can easily view and monitor the patient before, during and after scanning (e.g., with a scanner gantry camera)	○	○	○	○	○
I can easily communicate with the patient before, during and after scanning (e.g., with a CT scanner microphone and speaker system)	○	○	○	○	○
The CT scanner can physically support the weight of every patient encountered in my workplace	○	○	○	○	○
I can perform multiple consecutive scans without experiencing scanner hardware malfunctions (e.g., the patient table becomes unresponsive to commands)	○	○	○	○	○

24. Can you describe a specific challenge you have encountered with the CT scanner hardware?
Please provide as much detail as possible (optional)

25. Overall, I am satisfied the CT scanner hardware meets my needs as a CT radiographer: *

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

26. Can you describe any features that could enhance your CT scanning experience, with specific reference to the CT scanner hardware?
Optional

Prioritisation of need

You're almost done!

27. Rank the following CT system features in order of importance (1 being most important and 10 being least important) *

- Advanced imaging capabilities (e.g., dual-energy CT, perfusion imaging etc.)
- Cost-effectiveness
- Ease of maintenance and technical support
- Image quality
- Patient comfort features (e.g., wide-bore design, ambient lighting etc.)
- Patient communication (e.g., multi-lingual audio commands etc.)
- Radiation reduction capabilities
- Rapid scanning speed
- Teleradiology and remote operation capabilities
- User-friendly operation (e.g., automatic patient positioning assistance, automated post-processing algorithms etc.)

28. Rank the following issues based on their frequency of occurrence at your workplace (1 being most frequent and 1 being least frequent) *

- Environmental issues causing scanner malfunction (e.g., network connectivity, electrical supply etc.)
- Hardware issues causing scanner malfunction (e.g., control/button malfunction, patient table malfunction etc.)
- Software issues causing scanner malfunction (e.g., computer system failure)
- Unexpected maintenance causing scanner downtime (e.g., failed calibration, system-related image artifact etc.)
- Supply shortage causing scanner downtime (e.g., contrast agent/x-ray dye shortage, disposables, CT scanner components etc.)
- Regulatory issues or inspections causing scanner downtime
- Operator error causing scan failure (e.g., improper protocol selection, inadequate knowledge, improper contrast administration etc.)
- Failed contrast/x-ray dye injection causing scan failure (e.g., extravasation of contrast dye during scan etc.)
- Patient condition leading to scan failure (e.g., patient movement, breathing artifact resulting from a medical condition etc.)
- Miscommunication with patient leading to scan failure (e.g., patient movement or breathing artifact due to misunderstanding etc.)

29. Can you describe a scan failure, malfunction, or unanticipated downtime you have encountered?

Please give as much detail as possible (optional)

30. Can you name a CT system manufacturer whose scanners you have found to be most user-friendly?

Please give as much detail as possible on the features that appealed to you most (optional)

31. How important is it to enhance CT imaging services in your country? *

- ◯ Not important at all
- ◯ Somewhat important
- ◯ Moderately important
- ◯ Very important
- ◯ Extremely important

32. Additional comments/feedback: