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Faculty of Graduate Studies

**Radiation Dose Measurement among Brain Spectral CT
Pediatric Patients**

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**This thesis was submitted in partial fulfillment of the
requirements for the Master's degree in Computed
Tomography and Magnetic Resonance Imaging Sciences**

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Thesis Approval

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This thesis was defended successfully on 24/7/2025 and approved by:

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Declaration

I, the undersigned, declare that this MSc thesis is my original work and has not been submitted for a degree at any other university. Any expressions, views, research findings, references, and/or bibliographies used in this work have been explicitly acknowledged. As a result, I confirm that the intellectual content of this work was created by myself and was prepared with the assistance of my advisors.

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Dedication

First of all, I am thankful to God for this success, as well as to my family, who have always supported me in all circumstances. I couldn't have done it without their support and encouragement. Your sacrifices and faith in me have motivated me to reach my ambitions. I am grateful to everyone who wished me well and wealth. You've always been my beacon, and I appreciate it. I dedicate this effort to you with heartfelt gratitude and appreciation.

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Abstract

Introduction

CT technology, which was originally focused on static images, has evolved to incorporate advancements such as spectral CT, which improve diagnostic capabilities, particularly when analyzing complex anatomical regions such as the brain. The brain's complicated networks, which include the ventricular system and grey and white matter, are vital to its functionality, making CT scans necessary for detecting diseases such as traumatic brain injury (TBI) and brain tumors, especially in pediatric patients.

Purpose

The study's primary goal is to assess the radiation exposure of Spectral CT scans and multi-detector CT among pediatric patients who have undergone a brain CT examination. Create a customized phantom for pediatric head patients to estimate the correct dose for children.

Methods

This retrospective study examines the radiation exposure associated with pediatric brain computed tomography (CT) scans at Al-Rahma Friends Society and Rafedia Surgical Hospital from January to October 2024. Statistical analyses were employed to discern differences in radiation exposure between spectral CT and multi-slice CT scanners, highlighting the importance of standardized practices for minimizing radiation risks in pediatric imaging.

Results

The findings reveal that spectral CT scanners consistently deliver higher radiation doses compared to Philips MSCT scanners across various metrics such as Dose Length Product (DLP) and effective dose. The research also demonstrates that localizer-based dose estimation methods yield the highest and most precise estimates compared to nominal and phantom-based approaches.

Conclusion

This study examines the variability in radiation doses associated with pediatric head CT scans, highlighting significant discrepancies influenced by scanner type, patient age, body size, and dose estimation methodologies. The spectral CT scanners deliver significantly higher radiation doses than Philips MSCT across multiple dose metrics. The study calls for the establishment of consistent, scanner-specific protocols for pediatric head CT scans, advocating for the use of actual scan parameters to ensure accurate dose evaluations.

Keywords: CT brain pediatric indication, Spectral detector CT, multidetector CT, radiation dose metrics, CT dose.

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List of Abbreviations

Abbreviations	Title
AAPM	American Association of Physicists in Medicine
AAUP	Arab American University
AEC	Automatic exposure control
AI	Artificial Intelligence
ALARA	As low as reasonably achievable
ANOVA	Analysis of Variance
BEIR	Biological Effects of Ionizing Radiation
BMC	Bone Mineral Content
BMI	Body mass index
CCTA	Coronary computed tomography angiography
CNR	Contrast-to-noise ratio
CNS	Central nervous system
CSF	Cerebrospinal fluid
CT	Computed tomography
CTA	Computed tomography angiography
CTDI	Computed Tomography Dose Index
CTDI100	Computed Tomography Dose Index over 100 mm
CTDIvol	CT dose index volume
CTDIw	Weighted Computed Tomography Dose Index
DAI	Diffuse axonal injury
DLP	Dose-Length Product
DRLs	Diagnostic Reference Levels
DSCT	Dual-source CT
ED	Effective dose
EDLP	Effective Dose per Dose Length Product
EDs	Emergency departments

EICRP	The effective dose calculation method established by ICRP
EMI	Electric and Musical Industries
EURATOM	European Atomic Energy Community
FBP	Filtered back projection
GCS	Glasgow Coma Scale
GH	Government hospitals
GLM	General Linear Model
ICP	Intracranial pressure
ICRP	International Commission on Radiological Protection
IDRLs	Institutional Diagnostic Reference Levels
IEEE	The Institute of Electrical and Electronics Engineers
IVH	Intraventricular hemorrhage
mAS	Milliampere-seconds
McCollough	Type of image artifact seen in CT scans
MDCT	Multidetector computed tomography
mGy	Milligray
MIP	Maximum intensity projection
MPR	Multi-planar reconstruction
MRI	Magnetic Resonance Imaging
MSCT	Multislice CT
NICU	Neonatal intensive care unit
PACS	Picture Archiving and Communication System
PICU	Pediatric Intensive Care Unit
PMMA	Polymethyl Methacrylate
PVL	Periventricular leukomalacia
SD	Standard deviation
SDCT	Spectral Detector CT
SNR	Signal-to-noise ratio
SPSS	Statistical Package for the Social Sciences
SSDE	Spectral Shaping Dual Energy
SV	Sievert
TBI	Traumatic brain injury

US	Ultrasound imaging
WED	Water equivalent diameter
WEDmean	With the mean WED for each image set
WEDslice	WED for each individual slice

Chapter One: Introduction

1.1. Background

It is important to note that a CT scan typically administers a cumulative dose ranging from around 50 mGy to 60 mGy, which has been linked to an increased likelihood of developing conditions like leukaemia and brain tumours, significantly heightening health risks. Moreover, there is no definitive threshold established for cancer induction following radiation exposure; however, research indicates that children are more vulnerable to such risks compared to adults due to their higher rate of cell division and longer life expectancy (Araki et al., 2017).

Consequently, reducing unnecessary scans is fundamental in safeguarding children's health and well-being by minimizing their radiation exposure. By prioritizing judicious and selective utilization of CT scans, especially in pediatric cases, healthcare providers can help mitigate the potential adverse effects of radiation exposure in sensitive populations (Haghighi et al., 2014a).

Traumatic brain injury (TBI) is one of the most common causes of dysfunction and death in youngsters. This injury could be in the scalp, skull, or brain, so a computed tomography (CT) scan is needed. The seriousness of this injury is that the high vascularity of the scalp can cause fatal blood loss and therefore can cause haemorrhage shock without superficial bleeding (Araki et al., 2017).

Magnetic resonance imaging (MRI) for the case of TBI has prevented additional issues, including increased brain dysfunction and post-traumatic seizures, helped select the appropriate treatment, and allowed for a precise diagnosis. According to the studies, TBIs are the most common type of traumatic injury to causes irreversible impairment and death. A recent report stated a longitudinal fracture of the skull can be diagnosed with a high sensitivity using the combination of 2D and 3D CT (Araki et al., 2017).

Nervous system tumours are considered the second most common tumour in pediatrics after leukaemia, signifying a significant occurrence in childhood cancer cases. While brain cancer accounts for about 15% of total childhood cancer cases, it poses unique challenges due to its complexity. Utilizing MRI imaging is pivotal in diagnosing brain tumours, as it offers unparalleled soft tissue contrast, making it the preferred method for visualizing brain abnormalities. These tumours can develop in various regions of the brain, showcasing the diverse nature of pediatric brain tumours (Shaari et al., 2021).

Among the many types, embryonal tumours and brainstem gliomas collectively contribute to a considerable percentage of pediatric brain tumour cases, emphasizing the need for specialized treatment approaches. The occurrence of rare brain tumours such as choroid plexus tumours and schwannoma, known for their benign nature, underscores the diversity of tumour types encountered in pediatric patients. When considering treatment options, primary brain tumours often differ in approach from secondary tumours, like metastases, which are comparatively less common among pediatric cases. Such differences highlight the critical need for tailored and targeted therapies in managing pediatric brain tumour cases (Shaari et al., 2021).

CT scans are undoubtedly valuable diagnostic tools in the field of medicine, providing crucial insights into a patient's condition. However, it is important to recognize that these scans, particularly when focused on the brain, can have significant implications for the central nervous system (CNS). This concern is not new; in fact, it has evolved as studies have delved into the long-term effects of radiation exposure from various sources, including CT scans. One area of particular focus has been the impact on survivors of catastrophic events such as atomic bomb explosions and individuals exposed to radiation in occupational settings (Mehyar et al., 2019).

Understanding the risks associated with radiation exposure grows, this extends the concerns beyond immediate effects to considering the potential long-term consequences for individuals who have undergone radiation therapy for both malignant and benign tumours. Children, especially, are a vulnerable population, particularly those

who have undergone fluoroscopy-guided protocols or other radiographic diagnostic procedures involving ionizing radiation. It is worth noting that a single head CT scan, which may seem relatively routine, can expose a patient to a dose equivalent to that of 150 chest X-rays, highlighting the cumulative effect of such exposures (Mehyar et al., 2019).

Multiple studies have explored the relationship between ionizing radiation from diagnostic procedures and the subsequent development of CNS tumours. The spectrum of tumour types associated with post-exposure includes gliomas, schwannomas, and meningiomas, all of which pose serious health risks. Research has also shown a concerning trend whereby higher cumulative doses of radiation, exceeding 120 mGy, significantly elevate the likelihood of developing malignancies. Of particular concern are young children under the age of five, who are more susceptible to the harmful effects of radiation. For this age group, exposure to head CT scans not only increases the risk of malignancy but also elevates the probability of developing such conditions at a much higher rate compared to older individuals (Mehyar et al., 2019).

Therefore, it is crucial for healthcare providers to carefully weigh the benefits of performing CT scans against the potential risks, especially considering the correlation between repeated scans and the heightened likelihood of malignant tumour growth (Mehyar et al., 2019).

Computed Tomography Dose Index volume (CTDI volume) is a crucial parameter that reflects the intensity of the X-ray beam during imaging procedures. It is primarily regulated by factors such as tube current (mA), time (s), and pitch, specifically in helical scanning mode. CTDI volume plays a significant role in controlling the noise levels within the resulting CT images, thereby enhancing image quality and diagnostic accuracy (Tipnis et al., 2016).

In the realm of CT imaging, numerous factors come into play when deciding on the X-ray methods to be employed, which directly impact the extent of radiation exposure

encountered by the patient undergoing the procedure. It is crucial to thoroughly assess and take into account these factors in order to strike a balance between obtaining the vital diagnostic details and keeping radiation dosage at a minimum level, thus ensuring the safety and well-being of the individual receiving the imaging.

By carefully weighing these considerations, healthcare professionals can effectively optimize the diagnostic process, safeguarding patients from unnecessary radiation exposure while still achieving accurate and valuable diagnostic outcomes (Tipnis et al., 2016).

The radiation dose received during CT scans poses potential health risks to patients, particularly concerning the development of cancer in the future, especially in cases involving head CTs. Monitoring and managing the X-ray beam quality and closely monitoring CTDI volume readings, particularly in relation to phantom size, provides a standardized approach to assessing the radiation exposure for each patient undergoing any diagnostic examination. This meticulous approach ensures that patient safety and diagnostic efficacy remain paramount in the practice of radiology (Tipnis et al., 2016).

The brain is undoubtedly one of the most intricate and fascinating organs within the human body, housing a complex network of interconnected structures that play vital roles in various physiological functions. When the brain is examined in detail through different anatomical planes, such as axial, coronal, and sagittal sections, its deep components - including ventricles, grey and white matter structures, and deep grey nuclei - come into view, revealing the intricate design and functionality of this essential organ (Forstmann et al., 2015).

One of the brain's crucial features is the presence of ventricles, which serve as reservoirs for cerebrospinal fluid (CSF) produced by the choroid plexus. The CSF not only protects the brain from external impact but also facilitates communication and nutrient exchange between different parts of the brain through the interconnected ventricular system. This intricate network allows the CSF to flow through the brain,

reaching various regions, including the submeningeal area and the mediobasal region flanked by the lateral ventricles and corresponding grey matter nuclei (Forstmann et al., 2015).

The brain's intricate architecture encompasses distinct regions of grey matter nuclei that are delicately interwoven with networks of white matter pathways. These grey matter nuclei, characterized by their unique composition and functions, are essential components shaping the brain's overall structure and operational efficiency. The white matter, acting as a physical bridge, not only separates these key regions but also facilitates efficient communication and integration between them. The coordinated activity of grey matter nuclei and white matter pathways forms a cohesive and adaptive system that underpins the brain's capacity for electrical signal transmission and information processing.

Beyond their structural significance, the white matter components also serve a vital role in safeguarding and supporting the cerebral cortex, a brain region associated with high-level cognitive abilities, sensory processing, and precise motor coordination. This protective function of white matter ensures the uninterrupted functioning of the cerebral cortex, facilitating its intricate neural processes and intricate interconnections. The close interplay between grey matter nuclei and white matter pathways thus enables the seamless transmission of electric signals, fostering efficient information exchange and dynamic neural interactions throughout the brain's complex circuitry.

Furthermore, the white matter's role in supporting the cerebral cortex extends to enhancing the brain's resilience to external influences and maintaining its overall stability. By providing structural support and insulation, the white matter preserves the integrity of neural connections within the cerebral cortex, thereby promoting optimal cognitive performance and sensory perception. This intricate interdependence between grey matter and white matter elements illustrates the brain's remarkable capacity for adaptability and efficiency in processing information and responding to diverse stimuli.

Overall, the sophisticated interrelationship between grey matter nuclei and white matter pathways underscores the brain's remarkable structural complexity and functional versatility, highlighting the essential role they play in orchestrating the brain's intricate operations and facilitating higher-order cognitive functions essential for human experience and behaviour (Forstmann et al., 2015).

In essence, the complex interplay of grey and white matter structures, ventricular system, and CSF dynamics within the brain highlights the remarkable sophistication and functional diversity of this remarkable organ, underscoring its significance in maintaining overall human health and well-being (Forstmann et al., 2015). Therefore, the main indications that prompt the need for a CT scan include a range of medical concerns in the brain, such as seizures, brain trauma, and persistent headaches. Recognition of these specific indications is crucial in determining whether a scan is warranted, ultimately aiding in making informed decisions that can help minimize potential risks associated with radiation exposure.

CT has consistently upheld its position as a premier imaging technique owing to its exceptional performance, technological innovations, and continuous improvements in clinical applicability. Over the years, the progress in CT technology has been characterized by notable advancements in crucial aspects such as enhancing temporal resolution, providing comprehensive isotropic volume coverage, and effectively utilizing spectral information to differentiate and classify materials.

In the realm of medical imaging, the enduring relevance and significance of CT lie in its ability to offer unparalleled diagnostic precision and critical insights into a wide array of health conditions. The continuous evolution of CT technology has not only revolutionized diagnostic capabilities but has also significantly enhanced patient care and treatment outcomes. By pushing the boundaries of imaging quality and clinical utility, CT scanners have played a pivotal role in transforming healthcare practices and improving patient outcomes worldwide.

Furthermore, the integration of cutting-edge technologies like artificial intelligence and machine learning algorithms into CT systems has further bolstered their diagnostic accuracy and efficiency. These technological synergies enable radiologists and healthcare practitioners to extract detailed and meaningful information from CT scans, facilitating more accurate diagnoses and treatment planning.

Initially, the primary focus of CT innovation was on achieving high image quality for static objects. Subsequent improvements targeted at enhancing temporal resolution, introducing innovations like dual-source CT (DSCT), and implementing sophisticated algorithms. The trajectory of CT development then shifted towards expanding beyond purely anatomical imaging to encompass dual- or multi-energy data collection, resulting in the generation of spectral "colour" CT images. From a technological perspective, five key advancements in CT are notable: multislice CT (MSCT), wide-cone CT technologies, DSCT capabilities, spectral CT imaging, and advancements in helical/spiral data collection methodologies (Hsieh & Flohr, 2021).

Eliminating needless medical imaging, specifically CT scans, is a critical component of safeguarding children's health and well-being. This is paramount because it directly addresses the potential risks associated with radiation exposure, a concern that disproportionately affects vulnerable populations like children. Developing bodies are more susceptible to the long-term effects of radiation, underscoring the need for diligent management and a commitment to best practices (Haghighi et al., 2014a).

Healthcare providers bear a significant responsibility in mitigating potential harm. This involves implementing strategies to minimize radiation exposure while ensuring accurate diagnoses. The cornerstone of this approach is the judicious and selective use of CT scans, particularly in pediatric cases. This necessitates a shift towards prioritizing alternative imaging modalities when feasible, such as ultrasound or MRI, which do not utilize ionizing radiation. Furthermore, it requires meticulous consideration of each case, evaluating the clinical necessity of a CT scan against the potential risks. This involves

thorough clinical evaluations, detailed history taking, and careful assessment of symptoms to avoid unnecessary procedures. (Haghighi et al., 2014a)

Training and education are also essential. Healthcare professionals must stay abreast of the latest advancements in imaging technology, including dose reduction techniques and optimized scanning protocols. This includes continuous learning to enhance understanding of the ALARA principle ("As Low As Reasonably Achievable") in radiation safety and its practical application in clinical settings. By embracing these principles, healthcare providers can significantly contribute to protecting children from the potential detrimental effects of radiation, ensuring their healthy development and long-term well-being (Haghighi et al., 2014a).

In conclusion, the enduring success and prominence of CT as an imaging modality can be attributed to its continual technological advancements, clinical utility, and remarkable performance standards. This relentless pursuit of excellence in CT innovation not only underscores its vital role in modern healthcare but also underscores its potential for further advancements and contributions to the field of medical imaging (Hsieh & Flohr, 2021).

1.2. Problem Statement

Since the introduction of CT scans in the 1970s, there has been a noticeable surge in their demand across various medical specialties. Particularly, head CT scans without contrast have become a standard procedure in the emergency room, as well as in fields like neurology and neurosurgery. While these scans provide invaluable diagnostic insights for both medical professionals and patients, it is important to consider the implications of increased radiation exposure resulting from their frequent use (Bingyang et al., 2021; Haghighi et al., 2014a).

The continuous utilization of head CT scans without enhancement contributes significantly to the cumulative radiation dose in diagnostic radiology practice daily,

thereby raising concerns about the potential adverse effects of ionizing radiation on patients' health. Although CT represents just 11% of radiographic procedures, it is responsible for approximately 70% of the total radiation dose emanating from all radiographic modalities. Notably, the pediatric population has witnessed a notable uptick in the number of CT scans being performed for various diagnostic purposes, adding to the overall radiation burden on this particular group of patients (Bingyang et al., 2021).

Therefore, while CT scans offer unparalleled diagnostic capabilities, improved patient care, and enhanced medical outcomes, the medical community must remain vigilant regarding the judicious use of this imaging modality to mitigate unnecessary radiation exposure risks and ensure patient safety as a top priority (Bingyang et al., 2021).

Although CT scanning boasts several advantages and is considered the gold standard for diagnosing numerous diseases due to its detailed and precise imaging capabilities, it is important to highlight that one potential drawback is the significantly higher amount of radiation exposure compared to other radiographic procedures. For example, the radiation dose involved in a CT scan of the abdomen is estimated to be equivalent to undergoing anywhere from 100 to 250 radiographic chest examinations (Haghighi et al., 2014a).

This substantial dose can have serious implications, especially for children, as CT scans can result in cumulative radiation exposure levels of approximately 50 mGy and 60 mGy, increasing the risk of developing certain types of cancer. Specifically, the likelihood of developing leukaemia and brain cancer in children can triple when exposed to such doses.

It is particularly concerning to note that children are more vulnerable to the harmful effects of radiation compared to adults, with research indicating that a one-year-old child faces a significantly higher risk—up to 10 to 15 times more—of developing cancer when exposed to the same level of radiation as an adult. Therefore, while CT scans undoubtedly play a crucial role in medical diagnostics, it is essential to carefully consider the potential

risks associated with radiation exposure, especially when imaging children (Haghighi et al., 2014a).

Leukaemia is a predominant form of pediatric cancer in the West Bank, constituting 42% of cases in this region, showing the significant impact of this disease on the affected children and their families. In contrast, the Gaza Strip of Palestine has a slightly lower incidence of leukaemia at 26%, shedding light on potential regional variations in cancer epidemiology and healthcare accessibility (Halahleh et al., 2022).

The prevalence of nervous system and brain tumours, the second most common type of cancer in these areas, underscores the diverse spectrum of cancer diagnoses that children face, with 33% occurring in the West Bank and 16.5% in Gaza. This disparity could reflect differences in environmental exposures, genetic predispositions, or other contributing factors that warrant further investigation and targeted intervention strategies (Halahleh et al., 2022).

Furthermore, Non-Hodgkin's lymphoma emerges as the third most prevalent cancer type in both regions, with incidence rates of 17% in the West Bank and 17.1% in the Gaza Strip, underlining the urgency of comprehensive cancer care and support for pediatric patients across Palestine. This data underscores the pressing need for enhanced cancer surveillance programs, early detection initiatives, and tailored treatment protocols to effectively address the diverse landscape of pediatric cancer in the West Bank and the Gaza Strip (Halahleh et al., 2022).

1.3. Justification and Significance of the Study

In recent years, there has been a significant increase in the utilization of CT scans due to their exceptional diagnostic precision, rapid image acquisition, widespread availability, and cost-effectiveness. It's worth noting that CT scans constitute approximately 17% of all radiographic procedures conducted, with an even more striking statistic indicating that they contribute to 50% of the total collective effective dose of radiation in the United States (Nagayama et al., 2018).

The rise in demand for CT scans can be attributed to their ability to provide detailed and accurate imaging results, aiding healthcare providers in making timely and informed diagnoses. Furthermore, the relatively short time required to perform a CT scan compared to other imaging modalities is a crucial factor contributing to its popularity among both medical professionals and patients (Nagayama et al., 2018).

Considering the cost-effectiveness of CT scans in relation to their diagnostic capabilities, it is unsurprising that they have become integral in modern medical practice. The widespread availability of CT technology across healthcare facilities further contributes to its increased utilization, enabling patients to access this essential diagnostic tool more conveniently than ever before (Nagayama et al., 2018).

While the growing prevalence of CT scans underscores their importance in modern healthcare, it is essential to ensure that their utilization is balanced with appropriate radiation safety measures to minimize potential risks to patients. Healthcare providers must prioritize patient safety and well-being while harnessing the benefits offered by CT technology to deliver optimal care and diagnostic accuracy (Nagayama et al., 2018).

It is important to note that children are particularly vulnerable to ionizing radiation due to their rapidly growing and developing bodies, making them more sensitive to the potential risks associated with exposure than adults.

In medical imaging, healthcare providers need to consider these factors and tailor radiation doses accordingly to minimize any potential long-term harm to pediatric patients. Understanding the differences in sensitivity between children and adults can help healthcare professionals make more informed decisions when ordering imaging procedures, ensuring that the benefits of diagnostic information outweigh the associated risks (Mehyar et al., 2019).

By carefully weighing these factors, medical teams can provide the best possible care for patients while prioritizing their safety and well-being. It is therefore crucial to maintain a cautious approach when utilizing ionizing radiation in pediatric patients, taking into account their unique vulnerabilities and adjusting imaging protocols to safeguard their long-term health outcomes (Mehyar et al., 2019).

In Palestine, leukemia is the most prevalent type of cancer among pediatric patients. This type of cancer affects the blood and bone marrow and can be especially challenging for young children to overcome. The second most common cancer affecting children in Palestine is brain and nervous system cancer. These types of cancers can be particularly devastating due to their location and potential impact on cognitive and physical functions. Both leukemia and brain cancer in pediatric patients require specialized and comprehensive treatment approaches to improve outcomes and quality of life (Halahleh et al., 2022).

Additionally, raising awareness about the signs and symptoms of these cancers among parents and caregivers is crucial for early detection and timely intervention. Despite the challenges posed by these types of cancers, advancements in medical research and technology offer hope for better treatment options and improved survival rates for pediatric cancer patients in Palestine.

By supporting ongoing research efforts and promoting access to quality healthcare services, we can work towards reducing the burden of leukemia and brain cancer among children in the region and ultimately improve their overall well-being and prospects (Halahleh et al., 2022). So, ionizing radiation is a very concerning matter, especially in children.

1.4. Aim of the study

1. The main aim of the study is to assess the radiation dose of Spectral CT scans and multi-detector CT among pediatric patients who were scanned using brain CT examination.
2. Build a special phantom for pediatric head patients to estimate the exact dose for children who are examined in a Brain CT scan.

1.5. Study Objectives

1. Assess the radiation dose based on CTDI vol, DLP, and Effective dose of pediatric head in Spectral CT and Philips MSCT scanners for different protocols used to image the pediatric patients.
2. Assess the nominal radiation dose based on the size of the patient (if the technician is using a bigger field of view than the size of the head of the patient).
3. Measure the radiation dose (CTDI, DLP, and effective dose) in the fabricated phantom based on the averaged imaging protocol.
4. Compare the radiation dose (CTDI, DLP, and effective dose) between the reference standards protocol that must be scanned for the patient with that scanned by the technician.

1.6. Hypotheses of research

There is a significant difference between the radiation dose in spectral CT and Philips MSCT for pediatric brain imaging, and there is a noticeable effect in changing parameters on the image quality.

1.7. Questions of Research

1. How does Spectral CT affect the radiation dose on pediatric brain patients?

2. How the nominal localizer in CT image reduces the dose on pediatric brain patients.
3. Spectral CT delivers a radiation dose lower than Philips MSCT radiation dose.
4. How changing CT imaging parameters affects on radiation dose in CT imaging of pediatric patients.
5. How radiation dose that is measured in a fabricated pediatric head phantom higher to the radiation dose which is estimated in CT systems?

1.8. Outline

Upon perusing the remainder of this thesis, it will encounter the subsequent chapters presented sequentially: -

Chapter (2): Theoretical frameworks and previous Studies

Chapter (3): Materials and Methods of the study.

Chapter (4): The results.

Chapter (5): Discussion and conclusion.

Chapter Two: Theoretical frameworks and previous Studies

3.1. Introduction

The radiation dosage difference between multidetector CT scans and spectral computed tomography (SDCT) in the northwest West Bank is investigated in this study. This chapter will offer a thorough review of the literature, studying the theoretical basis of many conditions that affect children under the age of eighteen, as well as different types of CT.

A thorough examination of significant concepts constitutes an element of the theoretical framework that directs this investigation. It will define pediatric head illnesses, including information on their prevalence, causes, and different forms. Additionally, it covers current pediatric imaging practices, covering traditional imaging technologies and their drawbacks, emphasizing the necessity of more sophisticated strategies like SDCT.

The radiation dose using SDCT and MDCT will be the main topic of this section. The study examined published papers utilizing databases like PubMed and Google Scholar, as well as bibliographies, to obtain crucial data and pinpoint knowledge gaps in order to ensure a solid understanding of the measurement of radiation dose differentials. The efficacy of both systems in imaging the pediatric brain can be thoroughly examined by this multipronged research approach.

3.2. Theoretical frameworks

Radiologists find it difficult to recollect the stages of the development of the pediatric skull's anatomy. The varying nature and shifting appearance of sutures are the cause of this complexity. During the typical stage of development. Only the skull contains sutures, a kind of fibrous joint. The skull also contains synchondroses, a kind of hyaline

cartilage joint. Significant anatomical and morphological changes occur in these sutures and synchondroses in patients up to 4 years old, or neonates to toddlers (Idriz et al., 2015).

Accurately interpreting MDCT images of the pediatric skull requires a comprehension of these alterations. Unfortunately, there isn't much literature that describes how this anatomy looks on CT. All infants (less than a year old) and toddlers (between one and four years old) have the major sutures, which continue into adulthood. These sutures are the sagittal, coronal, lambdoid, and squamosal sutures (Idriz et al., 2015).

There is common knowledge of the architecture of these sutures because adult CT scans can easily view them. Even though the patient's age at closure varies, sutures show uniform anatomic positions and appearances. The first to close is the sagittal suture, which usually happens at the age of twenty-two (Idriz et al., 2015).

The lambdoid and squamosal sutures close at around twenty-six and sixty years of age, respectively, while the coronal suture closes at about twenty-four. In any of these sutures, premature fusion with osseous bridging is feasible. Craniosynostosis is a condition that alters the growth pattern of the skull, frequently leading to an atypically formed skull (Idriz et al., 2015).

All infants, toddlers, and some older children have normal developmental sutures, but adults do not. These sutures, especially asymmetrical ones, which are prevalent, are prone to being misinterpreted as fractures. The innominate, metopic, mendosal, sphenosquamosal, sphenofrontal, and occipitomastoid sutures are examples of normal developmental sutures. The metopic suture should close in almost all infants by nine months of age, yet it does so in as many as thirty-three percent of patients by three months. The sphenosquamosal suture usually closes by the age of six, though it may take up to ten (Idriz et al., 2015).

It is crucial to distinguish between normal sutural anatomy and fractures in both non-accidental head injuries and known traumatic episodes that warn the radiologist of possible harm. Injury results in 34% of survivors having severe impairment and a noteworthy overall mortality rate of 20%. The prognosis is further deteriorated by delayed diagnosis in these patients, whose trauma may not have been first noticed (Idriz et al., 2015).

3.3. Anatomy of the brain

It is a fascinating and complex subject that reveals the intricate workings of the central nervous system (CNS), which comprises both the brain and the spinal cord. This essential organ is responsible for a multitude of functions that govern the existence of human beings: thought, memory, emotion, touch, motor skills, vision, respiration, temperature regulation, hunger, and all bodily functions are intricately controlled by the brain (Nowinski, 2011).

Understanding the anatomy of the brain necessitates a look at its three primary parts: the cerebellum, the brainstem, and the cerebrum, each playing a unique and vital role in daily life. The cerebrum, often referred to as the largest part of the brain, is divided into two hemispheres—the left and the right—which together manage a wide array of functions (Forstmann et al., 2015).

These include the initiation and coordination of movement, the processing of sensory information such as temperature and touch, and the facilitation of vision and hearing. Moreover, the cerebrum plays a crucial role in speech and language, enabling us to communicate effectively. It is also responsible for higher cognitive functions such as judgment, critical thinking, problem-solving, various emotional responses, and the process of learning new information.

The complexity of the cerebrum illustrates just how essential it is for almost every aspect of human interactions with the world. Moving to the brainstem, which is located

in the middle section of the brain, it is composed of three parts: the medulla, the pons, and the midbrain. Each of these components is integral to maintaining basic life functions (Forstmann et al., 2015).

The brainstem oversees essential functions, including controlling eye and mouth movement, transmitting critical sensory information such as heat, pain, and sound, and regulating vital processes like hunger, breathing, heart function, and body temperature. Additionally, it manages involuntary muscle movements such as sneezing, coughing, vomiting, and swallowing, which are essential for survival. The brainstem, therefore, acts as a crucial relay station between the brain and the rest of the body, ensuring that vital functions occur seamlessly and without conscious effort.

Located at the posterior part of the head is the cerebellum, sometimes referred to as the "little brain." This structure is responsible for maintaining posture, balance, and equilibrium, which are essential for coordinated voluntary muscle movements. The cerebellum fine-tunes the physical actions, allowing humans to perform complex movements like playing a musical instrument or participating in sports with grace and precision. Its ability to integrate sensory information with motor commands is what helps navigate the human environment effectively (Anzidei et al., 2015).

Further dissecting the brain, a prominent structure nestled within the brainstem is called the pons. The pons is home to many control centres that govern the movements of the eyes and face, indicating its importance in facilitating expressions and communication. This region also plays a role in the regulation of sleep and arousal, influencing the overall alertness and cognitive functioning.

At the base of the brainstem lies the medulla, arguably the most critical area of the brain. It houses vital control centers responsible for regulating heart rate and lung function, making it indispensable for sustaining life. Damage to the medulla can have catastrophic consequences, underscoring the importance of this small yet powerful region.

Finally, the spinal cord serves as a vast network of nerve fibres that extends from the base of the brain down to the lower back. Acting as a communication highway, the spinal cord transmits and receives messages between the brain and the body, allowing for the coordination of reflexes and voluntary movements. This intricate network plays a crucial role in our ability to respond to stimuli and interact with our surroundings (Seeger, 2012)

Moreover, the frontal lobe, which constitutes the largest part of the brain, is located at the front of the head. It is heavily involved in movement, personality traits, judgment, decision-making, and some aspects of language processing. The frontal lobe is key in shaping how the person interacts with others, reflecting the character, choices, and cognitive abilities.

Additionally, the parietal lobe is instrumental in interpreting sensations such as touch and pain. When we perceive physical sensations, the parietal lobe processes these signals, allowing us to respond appropriately. For example, if we accidentally touch a hot surface, the parietal lobe quickly interprets this sensation as pain, prompting a reflexive withdrawal of the hand. This function not only protects us from harm but also helps us to understand our body's interaction with the environment (Toth, 2013).

In contrast, the occipital lobe, which is located at the back portion of the brain, is primarily responsible for our visual processing. This lobe receives and interprets signals from the eyes, allowing us to perceive and make sense of the visual information around us. The occipital lobe enables essential functions such as recognizing faces, interpreting colours, and perceiving motion, which are all vital for navigating and interacting with our surroundings effectively (Rehman & Al Khalili, 2019).

Moving to the temporal lobe, located on the sides of the brain, this region is equally important, contributing to various cognitive functions such as speech, memory, and the sense of smell. The temporal lobes house structures that are critical for language

comprehension and production, facilitating our ability to communicate effectively (Kiernan, 2012).

The anatomy of the brain illustrates not only the complexity of this organ but also its paramount importance in regulating virtually every aspect of human life. From the cerebrum, which manages high-level cognitive functions, to the brainstem, which oversees essential survival functions, and the cerebellum, which ensures the physical coordination, each component of the brain works in harmony to create the rich tapestry of human experience.

Understanding these structures and their functions not only enhances appreciation of the brain but also highlights the importance of maintaining its health through proper care and lifestyle choices. The parietal lobe, a crucial part of the brain situated in the upper middle section, plays a vital role in various cognitive and sensory functions. One of its primary responsibilities is object recognition, which involves the brain's ability to identify and differentiate various items in our environment.

3.3.1. Base Sutures of the Skull

The evaluation of the base of the skull proves to be quite challenging due to the primarily cartilaginous nature of the anterior region in postnatal development. Upon closer inspection, it becomes evident that the process of ossification initiates laterally in the ethmoidal labyrinth's ceiling and proceeds inwards toward the midline. Interestingly, by the age of six months, around half of the anterior skull base has already undergone full ossification, marking a significant milestone in skeletal development. As time progresses, this percentage gradually increases, with approximately 84% of the anterior skull base having completed the ossification process by the time the child reaches 24 months of age.

Therefore, it is crucial for healthcare professionals and researchers to bear in mind the unique developmental trajectory of the skull base, especially the anterior region, when

interpreting radiographic data or conducting anatomical studies. This intricate process of ossification highlights the intricate nature of cranial development postnatally, shedding light on the complexities involved in evaluating and understanding the structural changes that occur within the skull.

Moreover, this detailed knowledge of the timing and extent of ossification in different regions of the skull serves as a foundation for assessing normal growth patterns and identifying potential abnormalities or delays in skeletal maturation. By comprehensively studying the ossification patterns in the skull base, we can gain valuable insights into the intricate interplay between cartilaginous and bony structures, providing a deeper understanding of craniofacial development as a whole (Blaser et al., 2015).

Understanding the anatomy of the base of the skull is vital for accurate diagnosis, given that it is comprised of several synchondroses and sutures, including the occipitomastoid, parietomastoid, temporosphenoidal, lambdoid, and innominate sutures. The recognition of these basal sutures and their symmetry is crucial to preventing misdiagnosis, particularly in cases of trauma, where accurate identification is essential. The closure of the innominate suture by the age of four can pose challenges in distinguishing it from a skull base fracture in young children. One helpful approach to clarifying such cases is the use of reformatted images acquired obliquely to the original axial plane image, which can provide valuable insights.

The distinction between sutures and fractures is particularly challenging in children, given the varied appearance of their sutures. However, there are key guidelines that can aid in differentiation. Fractures typically exhibit bifurcation and non-sclerotic edges, often crossing the sutures and leading to diastasis. As fractures progress closer to a suture, they tend to widen, offering a potential clue for differentiation when evaluating skull base injuries. As such, a comprehensive understanding of both the anatomical landmarks and diagnostic criteria is essential for accurate assessment and management of skull base conditions, especially in pediatric cases where the diagnostic process can be particularly

complex due to the evolving nature of sutures and fractures in growing individuals (Sabu et al., 2025).

Overlying soft-tissue injuries, such as hematomas, can serve as helpful indirect indicators. Conversely, sutures connect additional sutures instead of Rather, cross them. Other than the previously mentioned exceptions, they do not produce diastasis of other sutures and maintain a comparatively constant diameter. The interdigitating or "zigzag" pattern of sutures has sclerotic boundaries (Sabu et al., 2025). As the most common pathologies that pediatric patients suffer from are fractures and brain haemorrhage, the next section will explain these two pathologies.

3.4. Fractures of Pediatric Skull

Pediatric fractures manifest in a wide array of forms, ranging from straightforward linear fractures to more intricate depressed or basilar fractures that are commonly observed in children. It is paramount to recognize that any skull fracture in a child could potentially indicate a grave underlying intracranial injury, underscoring the importance of swift diagnosis and appropriate medical intervention. Understanding the nuances between different fracture types is crucial for determining the most effective management strategies.

Linear fractures, visible as a simple line on the skull, typically exhibit milder characteristics in comparison to depressed fractures, which involve inward bone compression. Conversely, basilar fractures, which impact the skull's base, can jeopardize critical structures like the brainstem, necessitating meticulous attention and comprehensive treatment planning to mitigate potential complications effectively. Understanding these distinctions aids healthcare providers in accurately assessing the extent of injury and implementing the most effective interventions for each case. Furthermore, early identification of skull fractures in children allows for prompt monitoring and control of potential complications following trauma. Timely intervention

not only mitigates immediate risks but also plays a pivotal role in the long-term outcome and recovery for pediatric patients with head injuries.

In clinical practice, a detailed evaluation of the fracture type and its implications on intracranial structures informs the overall treatment strategy, emphasizing the need for a comprehensive and individualized approach to pediatric head trauma management (Bonfield et al., 2014).

When there arises concern regarding a potential brain injury, particularly in situations where a child exhibits an aberrant Glasgow Coma Scale (GCS) score or specific focal neurologic symptoms, it becomes crucial to incorporate a CT scan into the diagnostic process for a more comprehensive and accurate evaluation, rather than solely depending on conventional plain radiographs. Research findings indicate that approximately 50% of cases involving brain injuries may manifest without any associated skull fractures, underscoring the paramount importance of employing meticulous and thorough assessment techniques to detect any possible internal brain trauma.

In situations where suspicion arises regarding a potential brain injury, particularly when a child presents with an unusual GCS score or distinctive focal neurologic symptoms, it becomes paramount to incorporate a CT scan into the diagnostic process. This integration ensures a thorough and precise evaluation, emphasizing the importance of not relying solely on basic plain radiographs when assessing such cases.

Research findings indicate that approximately 50% of brain injuries might occur independently of any accompanying skull fractures, underscoring the critical need for comprehensive and detailed assessment methodologies to accurately detect internal brain damage in these complex scenarios. By adopting a meticulous and multidimensional approach to evaluation, clinicians can effectively pinpoint and address internal brain injuries even when external signs may not be readily apparent, showcasing the significance of advanced imaging techniques in modern medical practice. This approach not only enhances diagnostic accuracy but also facilitates targeted and timely

interventions, ultimately optimizing patient outcomes and improving overall prognosis in cases of suspected brain trauma.

Linear fractures specifically make up a considerable portion, estimated at 75%, of all reported skull fractures in children. While isolated linear skull fractures generally warrant treatment with pain management and outpatient monitoring, it is crucial to note that children under the age of two should receive specialized neurosurgical assessment and ongoing follow-up (Bonfield et al., 2014).

This targeted approach ensures that the unique needs and potential risks for this age group are adequately addressed, prioritizing their overall well-being and ensuring optimal recovery outcomes. Therefore, a comprehensive and individualized care plan is essential in managing skull fractures in children, especially when considering the diverse presentations and potential implications associated with these injuries.

Higher impact forces, such as those experienced in severe accidents or falls from significant heights, can lead to depressed skull fractures, a serious condition where a piece of the skull is pushed inwards more than its thickness, potentially damaging the underlying brain tissue.

It is crucial to understand that in cases of severe depressed skull fractures, immediate neurosurgical evaluation and intervention become paramount to accurately evaluate the extent of the injury and formulate a precise surgical plan for correction. This comprehensive approach may involve delicately lifting the depressed fragment and performing necessary surgical repairs to restore the natural contours of the skull, thereby alleviating any undue pressure on the brain and promoting optimal healing and recovery for the patient. It is important to note that the precision and timeliness of these neurosurgical interventions greatly influence the overall outcomes and prognosis for individuals suffering from such traumatic skull injuries (Atabaki, 2007).

Children who have sustained depressed skull fractures, a serious injury that can lead to long-term consequences for their health, are at an elevated risk of experiencing seizures post-trauma. The impact on the brain caused by such fractures can trigger abnormal electrical activity, potentially resulting in seizures. In order to avert this potential threat and safeguard the child's well-being, healthcare providers often recommend the use of anticonvulsant medications. These medications play a pivotal role in managing and controlling seizure activity, making them an essential component of the treatment plan.

By diligently administering these drugs in the early stages of intervention, physicians aim to protect the child's neurological functions and minimize the chances of complications arising from the skull fracture. Furthermore, close monitoring of the child's response to the anticonvulsants is vital to ensure that the prescribed medication effectively prevents seizures while avoiding harmful side effects. Overall, the judicious use of anticonvulsant therapy is instrumental in enhancing the child's recovery process and promoting optimal neurological outcomes following a depressed skull fracture (Atabaki, 2007).

Basilar skull fractures, which involve the base of the skull and may extend to the temporal bone or mastoid air cells, can present with specific clinical signs such as hemotympanum or the Battle sign, characterized by bruising behind the ear. These fractures can also result in venous sinus leakage, leading to the accumulation of blood around the eyes and forehead region, known as raccoon eyes or periorbital ecchymosis.

Recognizing these distinctive features is vital in diagnosing basilar skull fractures accurately and initiating appropriate management to address potential complications and ensure the patient's well-being.

Furthermore, it is crucial to note that in cases of basilar skull fractures, there may be a significant concern of additional symptoms, such as the leaking of cerebrospinal fluid (CSF) through the nose or ears. This specific type of fracture poses a unique challenge as conventional radiographs often fail to provide a clear identification. As a result, a

comprehensive evaluation through a head CT scan becomes essential whenever a clinical assessment raises suspicions of a potential basilar fracture (Pinto et al., 2012).

When presented with patients exhibiting symptoms indicative of basilar skull fractures, such as the troubling occurrence of cerebrospinal fluid (CSF) leakage, medical practitioners must emphasize the immediate necessity for thorough and rapid medical intervention. These individuals must be promptly admitted to a medical facility where they can receive specialized care and painstaking monitoring aimed at averting the potentially devastating complications that could arise if left unattended.

This underscores the grave importance of maintaining a high level of vigilance to address any emerging signs or complications. The looming risk of exacerbating neurological issues further underscores the critical nature of continuous monitoring and immediate intervention to avert any adverse outcomes. By promptly addressing any signs or symptoms indicative of basilar skull fractures, healthcare providers can play a crucial role in optimizing patient outcomes and preventing further harm.

Timely management is paramount in averting adverse outcomes, as unchecked basilar skull fractures can lead to detrimental consequences that may compromise the patient's well-being and recovery. By ensuring round-the-clock observation and diligent follow-up examinations, healthcare professionals can swiftly identify and treat any emerging issues or deteriorations in the patient's condition, thus safeguarding their neurological health and overall prognosis. Adhering to these stringent monitoring protocols is instrumental in optimizing patient outcomes and preventing long-term sequelae that could result from delayed or suboptimal care for basilar skull fractures.

In essence, the management of patients with basilar skull fractures extends beyond the initial diagnosis, requiring a systematic approach to ensure optimal outcomes. Careful monitoring, intervention, and treatment strategies must be in place to mitigate the risks associated with this type of fracture and prevent potential adverse outcomes. Thus,

continuous vigilance and appropriate medical interventions are crucial components of the care plan for individuals with basilar skull fractures (Bonfield et al., 2014).

3.5. Intracranial Damage

Research findings have shed light on the alarming reality faced by children who experience mild blunt trauma. It is reported that a notable percentage, estimated to be between 6% and 30%, may demonstrate signs of intracranial damage. This damage encompasses a spectrum of brain trauma, including but not limited to contusions, shearing injuries, diffuse axonal injury, subdural and epidural hemorrhages, as well as various other manifestations of intracranial bleeding. It is crucial to underscore the severity of these injuries, as they can often prove to be quite grave. For instance, rapid hemorrhages can precipitate the formation of epidural hematomas.

These hematomas primarily arise as a consequence of meningeal veins or arteries tearing, subsequently leading to the accumulation of blood between the dura mater and the skull. Such complications necessitate prompt and appropriate medical intervention to mitigate potentially catastrophic outcomes and ensure the affected children receive the care they urgently require. This underscores the critical importance of thorough evaluation and management strategies tailored to the specific needs of these vulnerable patients, with a keen focus on early detection and intervention to optimize outcomes and prevent further deterioration (Atabaki, 2007).

It is worth noting that epidural hematomas are commonly associated with temporal bone fractures, highlighting the serious nature of these injuries. Following the initial trauma, patients who have sustained epidural haemorrhages may go through a brief lucid interval lasting for a few hours, before their mental state deteriorates rapidly because of the accumulating pressure within the skull.

This underscores the critical importance of prompt diagnosis and appropriate medical intervention in cases of intracranial damage, as timely treatment can significantly

impact patient outcomes and overall prognosis. If not properly diagnosed and promptly addressed, the haemorrhages in question have the potential to prove fatal, underscoring the critical importance of close monitoring, immediate neurosurgical consultation, and thorough assessment for potential surgical evacuation in cases of epidural haemorrhages (Kyrnetskiy et al., 2005).

When managing conditions like isolated epidural bleeding, focusing on prioritizing interventions becomes paramount due to their profound influence on patient outcomes. After surgical evacuation, individuals with epidural hematomas usually experience a very optimistic prognosis, as these injuries commonly avoid affecting the brain's cortex. This protective element enables a more seamless recovery journey and improves the overall health outlook for the patient. Healthcare providers need to recognize the significance of timely and targeted interventions in these cases, as they can play a pivotal role in shaping the patient's recovery trajectory.

By placing a high emphasis on these specific interventions post-surgery, medical professionals can significantly enhance the likelihood of positive health outcomes for the individual. This approach not only speeds up the recovery process but also contributes to the overall well-being and prospects of the patient. Therefore, incorporating a strategic and proactive intervention plan following surgical procedures for epidural bleeding can make a substantial difference in the patient's recovery and long-term health status.

It is especially significant to highlight that among individuals who have suffered head trauma, children stand out as being particularly vulnerable to the development of subdural hematomas, a medical complication commonly linked to instances involving skull fractures. When blood pools in the subdural space in proximity to the brain's outer surface, subdural hematomas, which are often instigated by ruptures in the parasagittal bridging veins, exhibit a distinctive concave shape, thus emphasizing the unique characteristics of this condition and its specific symptoms. This heightened risk in pediatric cases accentuates the importance of prompt and accurate diagnosis and

treatment to mitigate potential complications and ensure optimal outcomes for affected individuals.

Understanding the intricate relationship between head injuries, subdural hematomas, and associated factors such as bridging vein tears allows healthcare practitioners to better assess and address such cases with targeted interventions and specialized care protocols tailored to the needs of pediatric patients. By elucidating these nuanced details and highlighting the complexities of subdural hematomas in the context of childhood head trauma, medical professionals can refine their approaches to managing such conditions effectively, ultimately leading to improved patient outcomes and enhanced overall healthcare outcomes in this specific demographic (Kyrnetskiy et al., 2005).

When managing subdural hematomas, it is imperative to implement meticulous oversight and execute precise interventions to effectively address the root causes and mitigate potential complications. This level of care and targeted approach plays a critical role in ensuring optimal outcomes for patients suffering from such conditions. Brain injuries resulting from abrupt acceleration or deceleration, commonly experienced in incidents like motor vehicle accidents, slips or falls, and instances of abusive trauma involving severe shaking, can lead to the development of diffuse axonal injury (DAI). DAI represents a serious form of neural damage caused by the stretching and tearing of nerve fibers within the brain, resulting in extensive harm that impacts various regions and functions of the brain.

The gravity of DAI necessitates prompt and comprehensive medical attention to alleviate symptoms, aid in the recovery process, and provide long-term support for individuals affected by this type of injury. Therefore, a thorough understanding of the mechanisms behind DAI, combined with targeted intervention strategies, is crucial in effectively managing and treating such complex neurological conditions. By continually assessing and adapting the treatment approach as needed, healthcare professionals can enhance the quality of care provided to patients with subdural hematomas and related

complications, ultimately improving their overall prognosis and quality of life (Atabaki, 2007).

When a patient presents with diffuse subarachnoid haemorrhage and cerebral edema, indicating potential diffuse axonal injury (DAI) characterized by extensive shearing damage to the brain's white matter, a cascade of complications may ensue. This includes the development of heightened intracranial pressure (ICP), a serious concern that can significantly impede the patient's recovery process and complicate treatment strategies. Notably, individuals who have recently experienced their initial concussion are particularly susceptible to DAI even from minor subsequent head injuries, as seen in cases of second impact syndrome.

The interplay between these factors underscores the critical need for vigilant monitoring and swift intervention to mitigate the adverse effects of DAI and manage associated risks effectively. Such comprehensive care must encompass close observation of neurological symptoms, diligent assessment of intracranial pressure dynamics, and tailored therapeutic approaches to address the complex repercussions of this multifaceted condition. Additionally, a proactive approach to educating patients, caregivers, and healthcare providers about the potential sequelae of DAI and the significance of preventive measures can play a pivotal role in enhancing overall outcomes and promoting long-term neurocognitive well-being.

By fostering a collaborative and proactive care environment that emphasizes early detection, targeted interventions, and holistic support, healthcare teams can strive to optimize patient outcomes and mitigate the far-reaching impact of DAI on individuals' lives and functional abilities.

In cases where there is suspicion of DAI, prompt medical intervention and close monitoring are essential to prevent further damage and complications. The presence of DAI can significantly impact the long-term prognosis of the individual, as it can lead to cognitive impairment, physical disability, and other neurological deficits.

Therefore, healthcare providers must be vigilant in identifying and managing DAI in patients with traumatic brain injuries, as timely and appropriate care can improve outcomes and quality of life. Additionally, ongoing rehabilitation and support may be necessary for individuals with DAI to help them regain lost function and adapt to any lasting disabilities resulting from the injury.

Patients who suffer from acute head trauma often develop cerebral contusions, which are injuries that most commonly affect the cortical tissue located beneath the area of impact. While small brain contusions may lead to minimal symptoms, severe cases can trigger cerebral edema, an increase in intracranial pressure, and more pronounced clinical manifestations.

In addition to contusions, cerebral hematomas, and skull fractures often coexist in patients with head injuries, further complicating their prognosis. These conditions are frequently observed in individuals who experience traumatic incidents resulting in head trauma. Moreover, chronic subdural hematomas, a distinct type of brain injury, can occur in a minority of cases following isolated venous haemorrhages (Ciochon et al., 2022).

Chronic subdural hematomas, a medical condition where blood accumulates outside the brain tissue, are notably distinguished by the development of persistent headaches in those affected. This accumulation of blood exerts pressure on the brain, leading to discomfort and potential complications. The prevalence of chronic subdural hematomas is notably higher in the elderly population as compared to children, likely attributed to age-related changes impacting the brain's structure and blood vessels.

In older individuals, the brain undergoes natural alterations that could predispose them to this condition. Moreover, age-related fragility in blood vessels may contribute to the increased risk of developing chronic subdural hematomas. Understanding these factors sheds light on why older adults are more susceptible to this health issue.

Consequently, clinicians and healthcare professionals should be vigilant in identifying and managing chronic subdural hematomas in older patients, aiming to mitigate potential complications and improve patient outcomes.

By recognizing the unique challenges faced by the elderly population, medical professionals can provide tailored interventions and care strategies, thus enhancing the quality of life for those affected by this condition (Ciochon et al., 2022). Therefore, recognizing and addressing such head injuries promptly is crucial in preventing potential complications and promoting better outcomes for patients of various age groups.

Five percent of patients with cerebral injuries and skull fractures are admitted to the hospital. Among this group, around one to three percent require specialized treatments such as intracranial pressure (ICP) monitoring, osmotic treatment, evacuation of cerebral hematomas, and administration of anticonvulsant medication. It is crucial to acknowledge that traumatic brain injuries (TBIs) often exhibit a dual-phase pattern of injury.

The primary insult typically occurs at the moment of impact, while the secondary insult tends to manifest within one to five days, with triggers commonly being hypotension and hypoxemia. This distinctive two-phase nature of TBIs underscores the critical importance of prompt and suitable medical interventions to help mitigate the potential risks associated with cerebral trauma, thereby improving overall patient outcomes and recovery prospects (Sun et al., 2017).

Furthermore, it is crucial to highlight the impact of secondary insults following severe TBI, as these instances are major contributors to morbidity rates in affected individuals. To effectively manage these risks and ensure optimal patient outcomes, strategies such as maintaining systolic blood pressure above the fifth percentile for age and aggressively sustaining PaO₂ levels greater than 100 mm Hg are crucial components of comprehensive care protocols for individuals with moderate or severe TBI (Araki et al., 2017).

By adhering to these guidelines and promptly addressing potential secondary insults, healthcare providers can significantly enhance the chances of successful recovery and minimize the adverse consequences associated with cerebral injuries.

3.6. Pediatric Imaging Modalities

Given that CT scanning stands out in the medical field as the go-to modality for discreetly pinpointing calcifications nestled within the intricate landscape of the brain, it is undeniably a popular choice due to its unparalleled accuracy when it comes to diagnostic imaging procedures. Notwithstanding the widespread acceptance and utilization of CT scans, there has been a noticeable shift in tendency among healthcare practitioners who are increasingly opting for ultrasound (US) as their primary neuroimaging tool, predominantly driven by heightened concerns surrounding the potential risks associated with radiation exposure inherent in CT imaging.

This emerging inclination towards prioritizing ultrasound over CT scans is amplified by the remarkable strides in ultrasound technology, which have substantially bolstered its efficacy in swiftly and precisely identifying calcifications, thereby enhancing diagnostic capabilities more efficiently (Smiljkovic et al., 2019).

However, it is important to note that while CT and ultrasound are preferred options for detecting calcifications, magnetic resonance imaging (MRI) stands out for its proficiency in identifying other crucial brain abnormalities that may not be as easily detected by CT or ultrasound. For instance, MRI excels in distinguishing features like cerebellar hypoplasia, gyration anomalies, and white matter alterations, making it a valuable imaging tool for comprehensive neuroimaging assessments (Smiljkovic et al., 2019)

The choice of the optimal imaging modality remains subjective and varies among medical practitioners, as different factors come into play when making this decision. Factors such as radiation risk, cost-effectiveness, and local accessibility of imaging technologies all play a significant role in influencing the choice between CT, US, or MRI for neuroimaging purposes.

Consequently, there is no definitive consensus on the ideal imaging modality, with individual healthcare providers weighing the pros and cons of each method based on their specific clinical requirements and priorities (Smiljkovic et al., 2019).

3.6.1. Ultrasound Imaging (US)

Ultrasound imaging of the pediatric head offers a diverse array of advantages and disadvantages in comparison with imaging modalities such as CT or MRI. When making the decision on the most appropriate imaging method for pediatric patients, it is essential to thoroughly assess and weigh these factors. An outstanding advantage of selecting radiation-free pediatric head ultrasound over other modalities like CT lies in its exceptional safety profile, particularly for newborns and infants. This safety profile is attributed to the elimination of ionizing radiation exposure, which is a common concern associated with CT scans.

By opting for ultrasound, healthcare providers can confidently avoid exposing young patients to the potential risks linked with radiation, providing a non-invasive and secure alternative for diagnostic imaging needs in this vulnerable population. Additionally, the dynamic and real-time capabilities of ultrasound imaging further enhance its utility in pediatric cases, allowing healthcare professionals to observe and assess anatomical structures and functions with precision and immediacy. Combining the benefits of safety, accuracy, and real-time monitoring, pediatric head ultrasound stands out as a valuable tool in the comprehensive care and imaging diagnostics for young patients, aligning with the paramount goal of ensuring their well-being and health (Thukral, 2015).

Its portability allows for on-the-spot evaluations at the patient's bedside, which proves particularly valuable in critical care settings like the neonatal intensive care unit (NICU) or Pediatric Intensive Care Unit (PICU). The instantaneous imaging capabilities of ultrasound facilitate dynamic assessments, including Doppler investigations to analyse blood flow. Moreover, the presence of open fontanelles, particularly the anterior fontanelle, serves as a natural acoustic window until closure around 12 to 18 months of age, offering clear visualization into the inner brain structures (Poussaint & Moeller, 2002).

From a cost perspective, pediatric head ultrasound is a cost-effective alternative to CT or MRI, usually not necessitating sedation during the procedure, unlike MRI, which often requires anaesthesia in young infants to reduce motion artifacts (Smiljkovic et al., 2019). Its quick completion time makes it ideal for swift initial evaluations of conditions such as periventricular leukomalacia (PVL), intraventricular haemorrhage (IVH), or hydrocephalus. However, it is important to note that ultrasound becomes ineffective once fontanelles close, hindering its ability to penetrate the skull effectively.

Additionally, its limited field of view may restrict the visibility of deeper brain regions, and the quality and interpretation of the images can greatly depend on the operator's expertise. While ultrasound may not offer as high a resolution as MRI, leading to potential limitations in detecting minor structural irregularities or lesions, it still holds significant value in applications such as neonatal intraventricular haemorrhage (IVH), hydrocephalus, PVL, ventriculomegaly, preliminary screening for birth defects, and monitoring identified anomalies (Poussaint & Moeller, 2002).

3.6.2. Magnetic Resonance Imaging (MRI)

Pediatric head MRI is a widely favored diagnostic tool due to its many advantageous features, one of the most prominent being its ability to deliver detailed

imaging without employing ionizing radiation. This attribute holds particular significance in pediatric cases, as children are more sensitive to radiation and have a longer life expectancy, thereby increasing the potential risks linked with cumulative exposure over time, in contrast to CT scans. Moreover, the enhanced soft tissue contrast provided by MRIs enables clear visualization of intricate structures such as the posterior fossa, ventricles, and the differentiation of gray and white matter, which might pose visualization challenges when examined via CT scans.

Additionally, the versatility of MRI technology permits imaging in multiple planes – namely axial, coronal, and sagittal – seamlessly capturing a comprehensive view of the anatomical structures without necessitating the patient to move between scans, thus facilitating a more convenient and thorough diagnostic process for both patients and healthcare providers. (Vogl et al., 2010).

Moreover, pediatric head MRIs excel in providing in-depth analysis of various brain pathologies, including congenital abnormalities, cancers, white matter disorders like leukodystrophies, conditions linked to epilepsy, and inflammatory or infectious disorders such as encephalitis. However, it is important to note that one drawback of pediatric MRI is the longer scan time, which can lead to an increased likelihood of motion artifacts, especially in young and uncooperative patients. To mitigate this issue, sedation is often required for infants and toddlers to ensure they remain still during the procedure, albeit presenting its own set of risks and challenges (Araki et al., 2017).

Furthermore, accessibility and cost can hinder the widespread use of MRI, especially in rural or emergency settings where immediate availability is crucial. Additionally, there are contraindications for certain children with metal implants or specific medical devices, such as pacemakers or cochlear implants, making them unsuitable candidates for MRI scans. Ultimately, while MRI offers numerous benefits for detailed imaging and diagnosis, CT scans remain the preferred choice for immediate emergencies due to their rapidity and effectiveness in detecting acute haemorrhages or skull fractures (Poussaint & Moeller, 2002).

3.6.3. Computed Tomography

The history of CT is rich with a series of groundbreaking technological advancements that have shaped modern medical imaging. It all began with the innovative invention of the very first CT scanner by the brilliant Nobel laureate Godfrey Hounsfield at Electric and Musical Industries (EMI), a milestone that revolutionized the way we visualize the human body. Initially founded on the translate-rotate geometry for capturing images, this foundational technology metamorphosed through successive generations, constantly pushing the boundaries of medical imaging capabilities.

The progression of CT technology reached a significant milestone in the 1980s with the advent of step-and-shot acquisition methodology, a pioneering approach that aimed to enhance imaging efficiency and accuracy. Despite its innovative nature, this method faced challenges like anatomical misregistrations, illustrating the continuous quest within the field for precision and perfection. Each refinement and upgrade within the realm of CT imaging represents a concerted effort to overcome obstacles and improve diagnostic capabilities, underscoring the relentless pursuit of excellence in medical technology.

Through each technological leap, the significance of CT scanning in modern healthcare has been augmented, fostering a deeper understanding of the human anatomy and facilitating early disease detection. The relentless pursuit of innovation within the realm of CT imaging has led to exponential improvements in image quality, diagnostic accuracy, and patient outcomes, highlighting the profound impact of Hounsfield's pioneering work on the evolution of medical imaging practices (Schulz et al., 2021).

A pivotal development in the 1990s was the advent of slip ring technology. This innovation enabled continuous rotation, allowing for the acquisition of complete abdominal or chest scans within a single breath-hold, significantly improving image quality and patient comfort. Further advancements followed rapidly: the four-detector raw CT scan in 1998 enhanced the capabilities of CT angiography.

This was succeeded by 16-detector row CT scanners in 2002 and the significant leap to 64-detector row CT scanners in 2004. The introduction of dual-detector and dual-source CT scanners in 2006, boasting a remarkable temporal resolution of 83 milliseconds, represented another substantial step forward. By 2010, the technology had progressed to 320-detector row CT scanners with a 16 cm wide detector array (Rubin, 2014).

The impact of CT on medical practice has been transformative. The introduction of CT scans revolutionized medical diagnosis, leading to significant advancements in understanding and managing various health conditions (Booij et al., 2020). The widespread adoption and utility of CT scans, particularly in economically developed regions, continue to grow (Walsh et al., 2014), solidifying their position as a vital diagnostic imaging modality.

3.6.4. Types of CT scan

Even though there was early speculation that magnetic resonance imaging (MRI) would entirely replace CT scans, CT imaging has managed to carve out its indispensable role within the realm of medical diagnostics, firmly establishing itself as a key component within hospital imaging departments. Over the years, the evolution of CT technology has been characterized by groundbreaking progress across various fronts, with notable strides being made in the fields of spectral CT, multi-detector CT, photon-counting CT, wide cone beam CT, helical or spiral data acquisition, and dual-source computed tomography (DSCT).

These advancements have not only enhanced the precision and efficacy of CT scans but have also allowed healthcare professionals to delve deeper into precise diagnostic imaging, thereby enabling them to make more informed decisions and offer more tailored treatment plans to patients. The continued prominence of CT imaging in today's medical landscape underscores its significance as a versatile and reliable tool, complementing the capabilities of other imaging modalities like MRI. As technology

continues to advance and the boundaries of medical imaging expand, the role of CT scans is poised to further evolve, offering new possibilities for improved patient care and diagnostic accuracy (Hsieh & Flohr, 2021).

2.6.4.1. Helical or Spiral Computed Tomography

The introduction of slip ring technology in 1990 was truly a game-changer for the field of CT scanning. This groundbreaking innovation completely transformed the way in which anatomical misregistration was handled, paving the way for more accurate and precise imaging techniques. Prior to this technological advancement, the limitations of traditional methods often resulted in incomplete or inaccurate scans due to the need for reverse rotation of the X-ray tube.

With the implementation of slip ring technology, a significant leap forward was made, as it allowed the X-ray tube to rotate continuously around the patient table. By eliminating the requirement for reverse rotation, this advancement enabled smoother and more efficient data acquisition, ultimately streamlining the entire scanning process. One of the most notable benefits of this innovation was the ability to capture volumetric data in a single seamless breath-hold.

This remarkable improvement marked a significant departure from the previous "step-and-shoot" method, which was considerably more time-consuming and limited in its scope. The transition to continuous rotation not only enhanced the speed and accuracy of imaging but also showcased a fundamental shift towards more comprehensive and detailed scans of the target organ. In essence, slip ring technology ushered in a new era of CT scanning, one that prioritized efficiency, precision, and enhanced diagnostic capabilities (Hsieh & Flohr, 2021; Trebuňová et al., 2017).

The acquisition of volume data formed the basis for advancements such as computed tomography angiography (CTA), transforming the diagnosis of vascular diseases. Furthermore, volume scanning facilitated the development of 3D imaging

techniques like maximum intensity projection (MIP) and multi-planar reconstruction (MPR). Spiral scanning offers several key advantages, including reduced scan times, uninterrupted data acquisition, and continuous radiation exposure, as the CT table moves through the gantry at a constant speed during the scan (Pace & Zarb, 2015).

2.6.4.2. Multidetector CT (MDCT)

The spatial resolution of CT scans exhibits an inverse relationship with the volume of the organ being scanned; larger volumes result in reduced resolution. The evolution of MDCT technology reflects this trade-off. Early CT scanners utilized only 2 detectors. Subsequent innovations led to scanners with 4, 8, 16, 32, 64, and 256 detectors. Currently, CT scanners with up to 320 detectors are available, notably within the Aquilion CT scanner family (Hsieh & Flohr, 2021; Seeram, 2015). A significant advancement resulting from the introduction of MDCT was the ability to acquire and visualize 3D images (Hsieh & Flohr, 2021).

2.6.4.3. Wide Cone CT

Wide cone beam CT, characterized by its broad z-coverage detector, revolutionized coronary computed tomography angiography (CCTA). This technology enables the complete scanning of the heart within a single rotation. Further clinical benefits include reduced radiation dose and improved volume perfusion measurements. However, wider z-coverage introduces challenges, primarily increased scatter radiation. To mitigate this, the implementation of post-patient collimation with a 2D focus effectively removes scatter radiation originating from the z-direction (Hsieh & Flohr, 2021).

2.6.4.4. Dual Source Computed Tomography (DSCT)

In coronary computed tomography angiography (CCTA), addressing irregular heart rates has continually presented a significant obstacle due to the constraints associated with temporal resolution. The traditional approach using wide cone CT scans often fails to achieve a rotation time of less than 0.25 seconds, resulting in a temporal resolution of 125s, which compromises the accuracy of imaging under these circumstances. However,

the remarkable advancements in medical imaging technology have heralded a new era with Dual Source Computed Tomography (DSCT) leading the charge.

DSCT introduces a pioneering setup featuring two X-ray tubes strategically placed 90 degrees apart, each equipped with double detectors. This innovative design of DSCT has proven to outstrip conventional methods by surmounting their limitations and elevating temporal resolution to unprecedented levels. By harnessing the power of dual X-ray tubes and double detectors, DSCT achieves a breakthrough in imaging capabilities, enabling healthcare professionals to capture highly detailed and precise images even in the presence of irregular heart rates.

The transformative impact of DSCT extends beyond mere enhancements; it fundamentally alters the landscape of cardiac imaging, empowering medical practitioners to diagnose and treat cardiovascular conditions with unprecedented accuracy and efficiency, ultimately improving patient outcomes and quality of care (Hsieh & Flohr, 2021).

What sets DSCT apart is its ability to effectively discriminate materials, a feat made possible by its implementation of two X-ray tubes operating at different energies - 80 and 140 kVp. This dual-energy approach enhances the diagnostic capabilities of DSCT, allowing for precise material differentiation and accurate imaging results (Mattison et al., 2016). Despite its revolutionary capabilities, DSCT scanners are not without their challenges. Issues like data truncation and radiation cross-scattering can sometimes pose obstacles in achieving optimal image quality. The presence of radiation cross-scattering, in particular, can lead to compromised material decomposition techniques and the generation of unwanted artifacts that may impact the contrast-to-noise ratio (CNR), thereby affecting the overall clarity and diagnostic value of the images produced (Hsieh & Flohr, 2021).

2.6.4.5. Dual-energy CT or Spectral CT

Dual-energy CT, also known as Spectral CT, has revolutionized the field of medical imaging by allowing for the collection of dual-energy data through various methods. These methods are typically categorized as either detector-driven or source-driven. In the source-driven approach, the detector itself does not provide spectrum information, requiring the modification of the input X-ray spectrum to generate different X-ray energy spectra for dual-energy acquisition (Hsieh & Flohr, 2021). Conversely, the detector-driven method entails keeping the X-ray source constant while the detector gathers necessary spectrum data. This distinction is crucial in understanding how dual-energy CT functions and the role each component plays in acquiring accurate imaging results (Garnett, 2020).

One of the significant advancements in dual-energy CT is the utilization of two distinct X-ray energy bands. This approach was first introduced with the launch of the first-generation dual-source CT system in 2006. By enhancing material discrimination capabilities, dual-energy CT methods have vastly improved image quality and diagnostic accuracy in various clinical settings (Garnett, 2020). Current techniques in dual-energy CT include fast voltage switching, dual-tube configurations with or without beam filtration, dual-layer detectors, split filter methods, and sequential scanning approaches.

Specifically, when employing a dual-layer detector with a single tube, polychromatic energy is produced by the X-ray tube, and data acquisition is facilitated by the unique dual-layer detector design. The top thin layer of the detector is designed to absorb low-energy photons and utilizes a scintillator based on yttrium, while the bottom thick layer is responsible for absorbing high-energy photons and contains $Gd_2O_2S_2$. This dual-layer detector setup enables precise differentiation between various materials and tissue types, leading to more accurate diagnostic information for healthcare professionals. Despite the numerous benefits of dual-energy CT, it is essential to acknowledge that there can be a trade-off in terms of extended reconstruction times when compared to traditional CT methods.

However, the ability to perform dual-energy assessments post-computed tomography scanning in all clinical scenarios outweighs the potential drawback of longer reconstruction durations. This balance between enhanced diagnostic capabilities and reconstruction time emphasizes the importance and impact of dual-energy CT in modern healthcare practices (Goo & Goo, 2017).

2.6.4.6. Photon Counting CT

Photon Counting Computed Tomography (CT) has emerged as a cutting-edge technology that utilizes photon counting detectors to achieve exceptional spatial resolution without electrical noise and extract spectral information inherently (Hsieh & Flohr, 2021). Previously evaluated a prototype of this innovative system over a decade ago. By employing photon counting detectors, also known as PCD CT, this advanced imaging technique has the potential to address common issues encountered in conventional CT imaging.

By reducing beam hardening artifacts, metallic artifacts, and the noise streaks caused by photon starvation, PCD CT significantly enhances image quality and diagnostic accuracy. This breakthrough technology not only revolutionizes the field of medical imaging but also paves the way for more precise and artifact-free CT scans, ultimately benefiting patients by providing clearer and more detailed diagnostic information to healthcare professionals. Furthermore, the continuous advancements in photon counting technology are contributing towards making CT imaging safer, more efficient, and increasingly reliable in clinical practice (Hsieh et al., 2020).

3.7. Brain CT scan

CT plays a crucial role in the assessment of intracranial pathological conditions, especially during the critical acute phase, where the saying "time is brain" holds true (Seeram, 2015; Vilela & Rowley, 2017). This imaging technique is instrumental in guiding not only current diagnostic processes but also future research endeavors and treatment strategies. In comparison to MRI, CT scans offer the advantage of rapid image

acquisition and minimal safety concerns. Although artifacts may arise due to patient motion, they are generally less pronounced compared to those seen in MRI scans (Seeram, 2015).

During a standard brain CT procedure, the scan typically commences from the superior aspect of the skull down to the vertex, providing a comprehensive view of the intracranial structures. Depending on the clinical context, healthcare providers may opt for various types of brain CT scans, including non-contrast CT scans, contrast-enhanced CT scans, and scans performed both with and without intravenous contrast administration, each tailored to specific diagnostic requirements (Romans, 2018).

The versatility of brain CT scans in differentiating various intracranial pathologies and providing essential information for clinical decision-making underscores its importance in modern medical practice. Additionally, the speed and safety profile of CT scans make them a valuable tool in emergencies where swift and accurate diagnosis is paramount for ensuring optimal patient outcomes. As technology continues to advance, the role of CT imaging in neurology remains ever-evolving, promising further enhancements in diagnostic accuracy and patient care.

Since the development of CT scans and the rapid advancements in this technology, the utilization of CT scans has seen a significant increase due to their effectiveness in diagnosing various medical conditions (Walsh et al., 2014). With CT scans accounting for approximately 70% of the total radiation dose from all imaging modalities while comprising only about 11% of radiographic exams, it is crucial to consider the potential risks associated with this imaging tool (Bingyang et al., 2021).

It is important to note that CT scans can deliver considerably higher radiation doses compared to conventional X-ray imaging modalities, with head and chest CT scans typically resulting in around 2 mSv and 10 mSv of radiation, respectively (Mehyar et al., 2019). To put this into perspective, the equivalent radiation exposure from these CT scans can be likened to approximately 150 X-rays for a chest scan and 750 X-rays for a head scan. When it comes to diagnosing brain tumors, especially in children, where brain

malignant tumors are relatively common, MRI stands out as the ideal modality due to its excellent tissue contrast and non-ionizing radiation properties (Shaari et al., 2021).

In contemporary helical scanners, the predominant metric used is CTDI_{vol}, known as Volume CTDI, derived directly from volumetric multidetector row systems. It involves adjusting for the pitch factor (P) to obtain the complete CTDI volume accurately, ensuring consistency irrespective of patient size or scan length. This standardized CTDI volume serves as a pivotal parameter for maintaining dose uniformity, enabling comparisons between various CT scanners and treatment modalities, and assisting in adherence to regulatory dosage constraints.

CTDI is indispensable for achieving consistent and reliable dose measurements across different CT systems, crucial for establishing dosage benchmarks and ensuring compliance with safety regulations. Manufacturers typically determine CTDI using a 100mm long ionization chamber within either a 16cm or 32cm diameter phantom, with the 16cm mode typically applied for head scans and the 32cm mode for body scans, covering regions such as the neck and beyond.

The dose-length product (DLP), which is calculated by multiplying the total radiation dosage by the length of the specific body part undergoing scanning, serves as a crucial measure in assessing the dose exposure during medical imaging examinations. This quantifiable value aids in evaluating the potential biological impact on the patient and is particularly useful in determining the efficacy of examining a particular anatomical region. It is an internationally recognized unit known as mGy cm.

$$DLP = CTDI \text{ vol} \times \text{scan length} \dots\dots\dots(\text{Arfat et al., 2024})$$

Despite its significance in dose assessment, the DLP does not encompass the variability in patient size or provide a direct measure of the absorbed radiation dose. To address this limitation, healthcare providers can resort to the size-specific dose estimate (SSDE) by considering the patient's anteroposterior and lateral dimensions to calculate a more personalized absorbed dose value.

In practice, determining the DLP requires initially measuring the CT dose index volume (CTDIvol) using a pencil ionization chamber inserted into a phantom of standardized dimensions. The DLP computation involves multiplying the CTDIvol by the scan length, with the latter being obtained from the CT scanner's software or imaging data. It's noteworthy that maintaining unit consistency, with CTDIvol in mGy and scan length in cm, is pivotal for ensuring the reliability of the resulting dose estimate.

Moreover, the radiation dose report generated by the CT scanner contains essential details regarding the examination, acting as a guide to the performed procedures and outlining the parameters used. Among the data provided, the CTDIvol stands out as a commonly referenced radiation dose metric found across various CT scans, aiding in understanding and monitoring the radiation exposure levels during diagnostic imaging (Arfat et al., 2024).

Understanding the link between CTDI and DLP is essential for effective management of radiation exposure in medical imaging procedures. DLP provides a comprehensive measurement of the total radiation dose delivered throughout the entire length of the scan, while CTDI specifically calculates the dose per unit volume of tissue. The relationship between these two metrics is fundamental to optimizing CT protocols to achieve high diagnostic efficacy while minimizing patient exposure to radiation. By carefully adjusting CTDI and DLP values, healthcare providers can tailor the radiation dose to meet the specific needs of individual patients.

It is important to note that the amount of radiation used, as represented by the DLP, is directly proportional to the effective dose received by the patient. This effective dose can be converted from DLP using specialized conversion factors that are tailored to different body regions. These conversion factors, denoted as 'k', account for variations in radiation absorption and biological implications across specific anatomical areas. By considering patient-specific factors such as age, body size, and BMI, healthcare providers

can further optimize dosage settings to account for variations in radiation sensitivity and image quality requirements.

$$\text{Effective dose} = \text{DLP (mGy.cm)} \times k \dots\dots\dots(\text{Arfat et al., 2024})$$

Moreover, the intended purpose of the CT scan, dictated by the clinical indication, influences the necessary dose settings. Conditions that require higher-resolution images may demand increased radiation doses to ensure diagnostic accuracy. It is crucial to strike a balance between optimizing CTDI and DLP settings to yield diagnostically valuable images while safeguarding patients from unnecessary radiation exposure.

In conclusion, the optimization of CTDI and DLP in CT imaging not only improves diagnostic accuracy but also plays a vital role in minimizing potential radiation risks to patients. By individualizing dose adjustments based on patient characteristics and clinical needs, healthcare professionals can achieve optimal diagnostic outcomes while prioritizing patient safety and wellbeing (Arfat et al., 2024).

Among pediatric brain tumors, brainstem gliomas and embryonal tumors account for a significant percentage, while benign schwannoma tumors and tumors of the choroid plexus are considered rare occurrences. The intricacies of different types of brain tumors emphasize the need for precise and accurate imaging techniques for their diagnosis and management (Shaari et al., 2021).

In pediatric imaging, prioritizing the reduction of radiation dose is of utmost importance due to the heightened sensitivity of pediatric patients compared to adults when exposed to the same dose, which can result in serious consequences such as cancer development or the potential transmission of genetic alterations to future generations (Eddy et al., 2021; Papadimitroulas et al., 2018). This elevated sensitivity in children can be attributed to their extended lifespan and the rapid rate of cell development, factors that surpass those of adults (Haghighi et al., 2014).

Particularly, children's brain, skin, thyroid, bone marrow, and breast tissues are among the most vulnerable to radiation exposure. Notably, the lenses of children are more susceptible to radiation-induced changes compared to those of adults. Therefore, specific and meticulous considerations must be taken into account when conducting imaging procedures on pediatric patients (Ploussi et al., 2018).

While CT scanning is undeniably vital in the realm of medicine, the associated radiation dose remains a significant concern, particularly in terms of the effective dose delivered to the patient. It is well understood that the quality of the images produced by CT scans and the effective dose of radiation are intricately linked, as achieving optimal image quality necessitates adequate exposure levels, which can inherently elevate the effective dose administered to the patient (Hu et al., 2022).

With the rapid advancements in computer technology, researchers have been able to harness the power of algorithms to enhance radiation dose reduction in CT scanning procedures, showcasing the potential of technology to improve patient outcomes and safety in medical imaging (Hu et al., 2022). Filtered back projection (FBP) is a widely utilized algorithm in modern computed tomography (CT) scanners for reconstructing images. This technique involves assembling image features during the reconstruction process through a process that is closely related to convolution. Before the actual back projection process takes place, each projection angle undergoes a convolution to reduce image shape artifacts and enhance the overall image quality.

Due to its ease of installation on CT computers and its ability to generate clear and detailed diagnostic images, FBP has become an indispensable tool in the medical imaging field (Hu et al., 2022). The fast processing speed of FBP also allows for the rapid reconstruction of large volumes of patient anatomy in a fraction of a second, highlighting its efficiency and reliability in the latest imaging scanners. Overall, the widespread adoption of filtered back projection has revolutionized the field of CT by delivering high-quality images quickly and accurately (Schofield et al., 2020). Lowering the current of

the X-ray tube is commonly employed within the field of CT scanning to effectively reduce the dose administered to patients.

It is important to emphasize that the implementation of this specific method, while crucial for various applications, may lead to an unintended compromise in image quality. This compromise may stem from the increase in noise as a result of the limited number of photons available in the imaging process. To overcome this challenge, the field of medical imaging has seen the development of numerous sophisticated solutions dedicated to improving the quality of images obtained at lower radiation doses.

Among the innovative solutions devised to address this issue, iterative reconstruction techniques have gained prominence for their ability to enhance image clarity and reduce artifacts. Additionally, the integration of advanced filtering mechanisms, such as sinogram-based methods, has offered significant improvements in noise reduction without sacrificing image sharpness. Moreover, cutting-edge advancements in image reconstruction technology have paved the way for the introduction of novel methods that directly impact the image processing pipeline, thereby optimizing the overall quality of the final output.

By leveraging these effective strategies, medical imaging professionals can navigate the delicate balance between minimizing radiation exposure and maintaining high-quality imaging outcomes. As technology continues to evolve, the continual refinement and integration of these approaches are vital for achieving optimal imaging results while ensuring patient safety and diagnostic accuracy.

These innovative techniques have been collectively classified as statistical methods, as they operate based on the statistical properties of the photons captured during the reconstruction phase of the imaging process, ultimately contributing to improved overall image quality and diagnostic accuracy (Chen et al., 2017; Karimi et al., 2016). The use of sinogram as a method in imaging processes has been noted for its superior effectiveness compared to other techniques. One key advantage is the reduction of noise from the raw data, which tends to be less complex than noise from the reconstructed image. This

difference in noise complexity underscores the strength of employing filtering techniques before image reconstruction rather than afterwards.

By implementing filtering on the sinogram and during the reconstruction process, not only is the approach quicker and simpler, but it also obviates the need to rely on the intricacies of the image reconstruction process. This efficiency not only enhances the overall speed of the process but also contributes to easier implementation, making it a preferred method in various imaging applications (Karimi et al., 2016).

3.7.1. Brain CT Scan Indications

Indications for a brain CT scan encompass a diverse array of conditions that necessitate thorough assessment. Among these indications are seizures, headaches, and traumatic brain injuries (TBI), which serve as primary criteria for determining the appropriateness of conducting a scan. However, the scope extends beyond these significant factors to include other crucial considerations, such as the presence of brain tumors.

Given the intricate nature of brain health, the decision-making process regarding the need for a CT scan requires a comprehensive evaluation that takes into account the multifaceted possibilities and implications that different conditions may pose. Incorporating a holistic approach to examining the various indications ensures that healthcare providers can accurately diagnose and treat patients while striving for optimal outcomes and well-informed decisions (Araki et al., 2017; Haghghi et al., 2014a).

TBI stands as the leading cause of disability and mortality in children, emphasizing the critical importance of understanding the intricacies of primary TBI classification. In essence, primary TBI can be categorized into three main types - extra-parenchymal, intra-parenchymal, and vascular injury - each presenting its own set of challenges and implications.

When assessing a potential TBI case, the necessity of a CT scan cannot be overstated, as it allows for a comprehensive evaluation of potential injuries within the scalp, brain, or bony skull. The highly vascular nature of the scalp further complicates matters, as it can exacerbate the situation by causing significant bleeding, ultimately leading to a catastrophic hemorrhage shock even in the absence of visible external bleeding.

The occurrence of TBI can stem from a variety of scenarios, ranging from falls and abusive injuries to accidents involving motor vehicles, underscoring the need for vigilant awareness and preventive measures in various settings. By delving deeper into the multifaceted nature of TBI and recognizing its diverse triggers and consequences, we can work towards enhancing our collective understanding and response to this critical issue that profoundly impacts the lives of children and families worldwide (Araki et al., 2017).

MRI has emerged as a pivotal tool in the realm of post-traumatic brain dysfunction and seizure prevention due to its ability to provide precise diagnostic information. By enhancing the accuracy of diagnosis and aiding in the selection of optimal therapeutic strategies, MRI plays a crucial role in improving patient outcomes following traumatic brain injuries (Araki et al., 2017).

In the field of pediatric oncology, brain tumors rank as the predominant solid tumor and a leading cause of cancer-related mortality. Surpassing all other malignancies after leukemia, brain tumors pose a significant challenge in pediatric care and treatment strategies (Cohen, 2022). Understandably, the clinical manifestation of these tumors relies heavily on the age of the patient and the specific location of the tumor within the brain.

When it comes to infants, symptoms of brain tumors often manifest in subtle yet important ways, such as macrocephaly, irritability, failure to thrive, developmental delays, and episodes of vomiting. These indicators, albeit somewhat nonspecific, are vital

clues for early detection and intervention in the pediatric population. Conversely, older children with brain tumors typically exhibit symptoms that are more localized and specific to the affected brain region.

These may include neurological deficits, such as sensory or motor disturbances, and signs of increased intracranial pressure resulting from the obstruction of normal cerebrospinal fluid circulation. The gradual accumulation of fluid in the brain leads to the development of hydrocephalus, a condition that demands prompt recognition and intervention to optimize clinical outcomes for affected children (Udaka & Packer, 2018).

3.7.2. Factors Affecting Dose

Due to the heightened sensitivity of children to radiation, it is essential to take into account the ALARA principle, commonly known as "as low as reasonably achievable." This principle aims to minimize unnecessary radiation exposure by optimizing and justifying the practice of radiation exposure. To adhere to the justification principle, it is crucial to ensure that any required examinations are appropriate and the benefits to the patient outweigh the potential risks. This assessment includes evaluating the necessity of the exam, considering alternative non-ionizing modalities, and confirming that the patient is receiving care at a suitable facility.

Furthermore, optimization measures involve aspects like controlling the scan length, utilizing iterative reconstruction techniques, and employing specific protocols designed for pediatric patients on modern CT scanners, which often incorporate lower kVp and mAs settings (Pennington, 2021). Factors affecting the dose in CT scans play a crucial role in TBI cases. While CT scans are vital for accurate diagnosis in TBI patients, it is essential to prioritize dose reduction and optimization to minimize potential risks. In some instances, particularly with young patients, factors such as anxiety, age, or encephalopathy-related injuries can lead to patient movement during the scan.

To mitigate this issue and prevent the need for repeated scans, sedation may be necessary. Additionally, extending the length of the brain scan to capture more detailed

images can inadvertently increase the radiation dose administered to the patient. Therefore, healthcare providers must carefully balance the need for comprehensive imaging with the imperative to limit radiation exposure, especially in vulnerable populations such as young TBI patients (Pennington, 2021).

3.8. Similar Studies

Tan et al. (2023) investigated the potential of 60-keV virtual monoenergetic images generated from dual-layer CT scans to reduce radiation exposure in pediatric cranial imaging while maintaining or improving image quality compared to conventional techniques. The study included 106 unenhanced pediatric head CT scans obtained using a dual-layer CT scanner (Tan et al., 2023). Patients were retrospectively divided into two groups (n=53 per group) based on the mAs setting used during acquisition: a 250 mAs group and a 180 mAs group. Dose-length product (DLP) values were recorded for each scan. Image quality metrics were calculated, including noise levels, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) (Tan et al., 2023).

Two experienced radiologists, blinded to the reconstruction technique and mAs setting, independently assessed image quality using a 5-point Likert scale. Statistical analysis employed ANOVA and Wilcoxon tests with adjustments for multiple comparisons (Tan et al., 2023). The mean DLP values were 717.47 mGy/cm (SD, 41.52) for the 250 mAs group and 520.74 mGy/cm (SD, 42) for the 180 mAs group. Significantly lower DLP values were observed in the 180 mAs group ($P < 0.001$). Across both mAs groups, 60-keV virtual monoenergetic images showed statistically significant improvements ($P \leq 0.001$) compared to conventional images in terms of reduced noise, increased SNR, improved CNR, and superior subjective image quality ratings (Tan et al., 2023).

No statistically significant differences ($P > .05$) were found between the 250 mAs and 180 mAs groups in terms of SNR, CNR, or subjective image quality assessments for the 60-keV virtual monoenergetic images (Tan et al., 2023).

It was concluded that the use of 60-keV virtual monoenergetic images from dual-layer CT scans in pediatric cranial imaging resulted in a 28% reduction in radiation dose, comparing the 180 mAs group to an implied control group with similar image quality at higher mAs without compromising image quality, as assessed by objective image metrics and subjective radiologist evaluation. This technique offers a promising approach to minimizing radiation exposure in pediatric head CT while preserving diagnostic image quality (Tan et al., 2023).

A study by Zatkuliakov et al. (2024) aimed to compare the radiation doses delivered during non-contrast-enhanced brain CT examinations performed on two different CT scanners. Specifically, the study compared the computed tomography dose index (CTDIvol), DLP, and effective dose (E) between the two scanners. The primary goal of this study was to assess the current radiation doses used in clinical practice, compare these doses to established reference values, and identify potential opportunities for dose optimization (Žatkuliaková et al., 2024).

Dose reports were accessed from the Picture Archiving and Communication System (PACS). The effective dose (E) for each examination was estimated using the DLP and a normalized conversion factor specific to the anatomical location (brain). The study concluded that utilizing modern CT equipment for non-contrast-enhanced brain examinations resulted in reduced radiation exposure by about 30% for patients (Žatkuliaková et al., 2024).

Inoue et al. (2023) investigated age-based ED estimation techniques in pediatric brain CT. The retrospective analysis included 980 brain CT images acquired from children for various clinical indications. To determine the age-specific conversion factors, two interpolation methods were employed: a curve-fitting technique and a linear interpolation approach. These methods utilized conversion factors provided by the International Commission on Radiological Protection (ICRP) for ages 0, 1, 5, and 10 years.

The conversion factor for each patient's age (in integer years) was derived using these methods. A simpler method involved directly applying the ICRP conversion factor corresponding to the nearest age. The study compared the ED estimations obtained from these different approaches. In conclusion, even while DLP rises with age, the ED in pediatric brain CT reduces. It is expected that calculating the conversion factor using a curve at each age will help estimate the ED in pediatric CT based on age (Inoue et al., 2023).

Another study of Malchair & Maccia (2020) aimed to provide useful guidance for children's CT scanner dosage. The study results in the conclusion that medical exposures are a top concern for radiological protection and that every attempt should be made to limit the increase in doses resulting from ionizing radiation diagnostic exams, particularly CT. The two most crucial concerns in pediatric imaging are obtaining high-quality images for diagnosis and preventing examination repetition (Malchair & Maccia, 2020).

This publication details methods for optimizing diagnostic image quality in CT while simultaneously minimizing patient radiation exposure. Optimizing the technical characteristics of CT examinations requires a proactive and voluntary approach from radiologists, encompassing both equipment settings and examination protocols. A straightforward control measure involves assessing DRLs for each CT scanner and institution, ensuring that they are appropriate and regularly reviewed. The efficacy of these optimization strategies should be continuously monitored and evaluated (Malchair & Maccia, 2020).

To effectively manage patient radiation dose, the formation of a dedicated core team is crucial. This team, as recommended by the new EURATOM (The European atomic energy organization) directive, should ideally comprise radiologists, medical physicists, and radiology technicians. This multidisciplinary approach ensures comprehensive oversight of the entire optimization process, from equipment calibration and protocol development to image interpretation and dose reporting. The team's responsibilities

include reviewing optimization protocols, analyzing dose data, and identifying areas for improvement (Malchair & Maccia, 2020).

Furthermore, all CT operators require thorough training on patient radiation safety. This training must encompass safe operating procedures for CT scanners, emphasizing proper scan parameters, and practical instruction on balancing image quality with the minimization of radiation dose. The training should cover techniques for optimizing scan protocols for different patient types and clinical indications, alongside understanding and applying the principles of ALARA (As Low As Reasonably Achievable). Regular competency assessments should be implemented to maintain high standards of radiation safety practices (Malchair & Maccia, 2020).

In this paper, they have examined every approach to pediatric CT dosage optimization. The optimization procedure to obtain a diagnostic image quality with the least amount of patient exposure can benefit from the methods reviewed in this publication. Radiologists must adopt a volunteer mindset to truly optimize the technical aspects of the exams to do that in practice (Malchair & Maccia, 2020).

In Tan et al (2021) study, a retrospective analysis was conducted across four emergency departments within a healthcare network: three general hospitals and one pediatric. The study population comprised pediatric patients under 16 years of age. Demographic data, diagnoses, CTDI_{vol}, and DLP were collected for each patient. The effective dose was subsequently calculated from the DLP values using k-coefficients. These k-coefficients were derived using a 16 cm head CT dose phantom, employing a standardized methodology to convert DLP to effective dose, allowing for comparison across different CT scanners and protocols (Tan et al., 2021).

Their study aimed to compare radiation doses from CT brain investigations conducted in pediatric and general emergency departments (EDs). The specific objective was to determine the proportion of these CT brain scans that fell within the reference levels recommended by the International Commission on Radiological Protection

(ICRP). The study involves retrospective analysis of patient data, including age, clinical indication for the scan, and the measured CTDI_{vol} or DLP for each scan.

Data analysis would compare the average radiation doses and the proportion of scans within ICRP reference levels between the pediatric and general ED populations. The study's findings will contribute to understanding radiation dose variations in different ED settings and inform strategies to optimize radiation protection in pediatric CT brain imaging (Tan et al., 2021).

Radiation exposures from CT brain examinations conducted in general emergency departments were significantly higher than in other settings. A substantial portion—more than half—of these examinations exceeded the International Commission on Radiological Protection (ICRP) recommended dose range. This highlights a need for improved radiation safety protocols within emergency departments. The development and implementation of DRLs serve as a crucial clinical guideline for CT examinations, particularly for pediatric patients, enabling a more standardized approach to radiation dose optimization and helping minimize the risks associated with these procedures (Tan et al., 2021).

They concluded that the contributing factors to the elevated radiation doses in emergency department CT brain scans are warranted, and strategies for improving protocols and training should be explored to reduce unnecessary radiation exposure. The use of DRLs should be accompanied by continuous monitoring and quality assurance programs to ensure their effectiveness in reducing radiation doses and maintaining optimal image quality (Tan et al., 2021).

A study by Atiya (2024) aimed to evaluate radiation risks in pediatric patients during brain CT diagnostic procedures at government hospitals (GH) in the West Bank in Palestine, by calculating key radiology parameters, specifically CTDI_{vol} and DLP. These calculated parameters were compared to international dose reference levels. The study's focus is on the critical need to minimize ionizing radiation exposure in children, particularly during brain CT examinations (Atiya, 2024).

The study included 2160 samples of pediatric patients who underwent brain computed tomography (CT) scans without contrast media. The objective was to determine the median and third quartile mean values of CT Dose Index Volume (CTDI_{vol}) and Dose Length Product (DLP) for different age groups. Data were collected and analyzed for the following pediatric age groups: >1 year, 1-5 years, 5-10 years, 10-15 years, and 15-18 years old. The calculated median and third quartile mean CTDI_{vol} and DLP values for each age group were then statistically compared ($p \leq 0.05$) to established international reference values from (Atiya, 2024).

This study concluded that Dose values for both DLP and CTDI_{vol} demonstrated significant variability across different CT devices. This variation stems from differences in established protocols, technical implementation, and specific scan parameter values. Key parameters contributing to this variability include kilovoltage peak (kVp), milliamperere-seconds (mAs), scan time, slice thickness, and pitch. These differences ultimately result in varying radiation exposure doses for ostensibly identical CT examinations (Atiya, 2024).

A notable finding emerged from a study comparing radiation doses in pediatric brain CT scans conducted at West Bank and those performed in other nations. Children receiving brain CT scans within exhibited significantly higher radiation doses compared to their counterparts in other countries. Intriguingly, even when employing the same model of CT scanner, substantial variation in the CTDI_{vol} radiation dose index was observed across different hospitals within GHS. This highlights the significant impact of protocol adherence, technician training, and quality control measures on actual radiation delivery during CT examinations. Further investigation is warranted to identify specific contributing factors and implement standardized protocols to minimize unnecessary radiation exposure (Atiya, 2024).

Research by Kiani et al (2023) measured how much radiation children's brains receive during CT scans, the overall dose of radiation absorbed, the quality of the images

produced, and the potential risk of developing cancer caused by the radiation exposure. These are critical factors because while CT scans are valuable diagnostic tools, they also expose young patients to radiation that can have long-term health effects (Kiani & Chaparian, 2023).

Their study involved 179 children under the age of 12 who underwent brain scans without contrast dye. Of these children, 99 were boys and 80 were girls. The children were sorted into four age groups to see if age impacted radiation dose and image quality: children aged 1 year or younger, those between 2 and 5 years, those from 6 to 9 years, and children aged 10 to 12. This division helps reveal how differences in age and size affect radiation exposure and image clarity. Smaller children generally require less radiation, but the best practices in imaging need to be tested across these groups (Kiani & Chaparian, 2023).

To measure radiation doses to specific organs and the overall effective dose, researchers used a tool called the ImpactDose system. This software calculates how much radiation each part of the brain and other nearby tissues absorbs during the scan. It also estimates the total risk of radiation leading to future health problems, like cancer. To do this, the study utilized risk assessment models derived from the BEIR VII report, a well-respected source that provides estimates on the probability of developing radiation-related cancer over a lifetime (Kiani & Chaparian, 2023).

In addition, the study did not just focus on radiation amounts. It also examined the quality of the images produced. Factors such as noise, which appears as graininess in images, and the clarity of details are vital for accurate diagnosis. SNR — representing how well image signals stand out from background noise — was measured. A high SNR means clearer images. Conversely, the CNR was evaluated to see how well different tissues can be distinguished from each other in the scans. These parameters help determine if the imaging setup provides enough detail for doctors to accurately identify abnormalities like tumors, bleeding, or other damage (Kiani & Chaparian, 2023).

The main finding of this study suggests that children receiving brain CT scans face a measurable increase in cancer risk over their lifetime. While the benefits of accurate diagnosis are unquestionable, the potential for radiation-induced harm must be carefully considered. Reducing unnecessary radiation exposure becomes extremely important, especially because children are more vulnerable to its harmful effects (Kiani & Chaparian, 2023).

The study emphasizes the importance of finding ways to minimize radiation in pediatric imaging. Ensuring that each scan delivers just enough radiation for a clear image, without excess, can improve safety. Future approaches might include developing newer technology that uses less radiation or refining existing protocols to better suit children's needs. The goal is to obtain high-quality images that support diagnosis, while also protecting young patients from avoidable radiation risks. This research underscores the need for continuous review and improvement of imaging practices in pediatric medicine to safeguard children's health now and in the future (Kiani & Chaparian, 2023).

A study by Seibert et al. (2014) evaluated the volume CTDI_{vol} and DLP, commonly reported for clinical CT examinations, are unreliable indicators of actual patient dose. Significant underestimation or overestimation can occur when the patient's body size deviates from the standard 16 cm or 32 cm diameter phantoms used in CTDI_{vol} measurements. This discrepancy is particularly problematic in pediatric imaging (Seibert et al., 2014).

The variability stems from inconsistencies among manufacturers; some utilize the larger 32 cm phantom as the reference for CTDI_{vol}, while others employ the smaller 16 cm phantom. This lack of standardization leads to inaccurate dose estimations based on these parameters alone. Therefore, relying solely on CTDI_{vol} and DLP for assessing patient dose, especially in pediatric populations, is inaccurate and may lead to misinterpretations of radiation exposure. More sophisticated methods, accounting for individual patient anatomy and scan parameters, are necessary for accurate patient dose assessment (Seibert et al., 2014).

A clinical case was presented involving a pediatric patient who underwent both presurgical and postsurgical CT examinations. A significant four-fold variation in CTDIvol was observed between these two scans. This variation is notable despite the estimated absorbed dose remaining relatively consistent between the two examinations.

To investigate this discrepancy, size-specific dose estimates (SSDEs) were generated using methodologies outlined by the American Association of Physicists in Medicine (AAPM). These SSDEs were then compared to the corresponding CTDIvol measurements to analyze the differences and potentially explain the observed disparity between the CTDIvol values and the actual patient dose. Further details regarding the patient's age, weight, specific CT protocols used for each scan, and the methods employed for dose estimation are needed for a complete analysis (Seibert et al., 2014).

The result was that the implementation of Spectral Shaping Dual Energy (SSDE) technology yielded a significant decrease in the variation observed in radiation dose estimates of CTDIvol during the clinical study. This reduction in differences enhanced the accuracy and reliability of dose estimations, enhancing the feasibility of comparing dose levels among different CT scanners in a more genuine and practical manner. Consequently, healthcare providers can now make more informed decisions based on these more realistic dose estimates, ultimately leading to improved patient care and safety (Seibert et al., 2014).

The notable impact of SSDE on standardizing dose evaluations across various scanning devices serves to enhance the quality and consistency of diagnostic imaging procedures, ensuring that patients receive the appropriate level of radiation exposure during scans while maintaining diagnostic efficacy. The integration of SSDE into clinical practice represents a significant advancement in radiology, underscoring the importance of technological innovations in optimizing healthcare delivery and patient outcomes. Moreover, this standardization in dose estimations not only benefits current clinical

practices but also paves the way for future advancements in imaging technology and radiation safety protocols (Seibert et al., 2014).

They concluded, the successful integration of SSDE technology in the clinical setting marks a turning point in enhancing the precision and reliability of radiation dose estimations, thus fostering a more effective and patient-centred approach to medical imaging. When reporting and comparing patient dose indices, the SSDE metric outperforms the CTDIvol meter in terms of radiation dose estimates (Seibert et al., 2014).

Haghighi et al. (2014) analysed the occurrence of atypical outcomes in brain CT scans conducted on pediatric patients and investigated the underlying causes prompting these scans. This case series comprises detailed demographic profiles and CT scan results from a cohort of 167 individuals who were referred to Taba Radiology Centre in Shiraz over a span from April 2010 to August 2011 (Haghighi et al., 2014b).

Pertinent information regarding the patients' medical grievances was collated through direct phone conversations. Various analytical techniques, including descriptive statistics and Pearson chi-squared tests, were employed to explore the collected data. For this study, any P-values below 0.05 were deemed statistically significant (Haghighi et al., 2014b).

The findings revealed that out of the 167 patients studied, 84 were males, constituting approximately half of the total cohort, with an average age of 12.5 years. Notably, a total of 20 individuals exhibited abnormal CT scan results, depicting a prevalence rate of nearly 12%. Among the most frequently detected irregular findings were arachnoid cysts, cerebral hemorrhages, atrophic changes, hydrocephaly, and congenital underdevelopment, each accounting for significant proportions (Haghighi et al., 2014b).

The primary complaints reported by the patients predominantly centered around headaches, head injuries, and seizures, with headaches appearing as the leading cause among the trio. Surprisingly, the likelihood of detecting anomalous CT scans in patients reporting headaches was notably lower compared to those presenting with other medical issues. This substantial disparity was statistically validated, emphasizing the importance of accurately identifying the rationale behind imaging requisitions to avert unwarranted procedures and mitigate associated risks effectively (Haghighi et al., 2014b).

Inoue et al (2022) explored the relationship between head size and radiation exposure in pediatric brain CT scans, specifically examining the effectiveness of automatic exposure control (AEC) in managing radiation dosage. Experimental investigations using phantom models were conducted to compare image noise levels with and without AEC, revealing that AEC effectively minimized noise discrepancies across different slice sizes (Inoue et al., 2022).

Subsequently, a thorough retrospective analysis encompassing 980 pediatric brain CT scans was carried out, during which tube current measurements were taken in conjunction with AEC. Head size was quantified using the water equivalent diameter (WED), with the mean WED for each image set (WED_{mean}) and WED for each individual slice (WED_{slice}) serving as key analytical metrics. The study scrutinized the relationship between the volume CTDI_{vol} and WED_{mean} in the image-set-based investigation, while in the slice-based analysis, tube current variations were compared across different WED_{slices} observed in 20 selected image sets (Inoue et al., 2022).

Furthermore, a gender-based comparison was performed between male and female patients, controlling for age, weight, and WED_{mean}, revealing a slight but statistically significant elevation in both CTDI_{vol} and WED_{mean} in males. However, these differences were not found to be sex-dependent after adjusting for WED_{mean}. Noteworthy, the study highlighted the effectiveness of AEC in tailoring radiation dosages to individual subjects and specific slice positions based on head size variations,

thereby recommending the routine utilization of AEC in pediatric brain CT scans for optimal dose management and radiation safety (Inoue et al., 2022).

Brady et al. (2015) investigated a method for computing effective dosage in CT scans by integrating size-specific dose estimates and enhancing the current approach through the incorporation of dose-length product (DLP). The study involved the analysis of a comprehensive dataset comprising 352 chest and 241 abdominopelvic CT images. To estimate organ dose in the chest and abdomen-pelvis regions accurately, a size-specific dose estimate was applied. Subsequently, organ doses were averaged within different patient weight categories, and these values were then used to determine effective doses through the utilization of the International Commission on Radiological Protection (ICRP) report 103 technique incorporating tissue-weighting factors (EICRP). The calculation of effective doses for the chest and abdominopelvic regions was based on the application of population-averaged CT examination DLP and established k-coefficients ($EDLP = k \times DLP$) (Brady et al., 2015).

Analysis revealed an average difference of 21% (1.4 vs. 1.1) in the chest and 42% (2.4 vs. 3.4) in the abdomen and pelvis between EDLP and EICRP. These disparities stemmed from the use of k-coefficients that did not factor in pitch variations other than unity, were determined using a 32-cm diameter CT dose index (CTDI) phantom for pediatric CT scans, and relied on ICRP 60 tissue weighting factors. Subsequent adjustments were made to account for pitch factor, the appropriate CTDI phantom size, and ICRP 103 tissue-weighting parameters, resulting in a significant improvement in EDLP alignment with EICRP, with a margin of over 7% (1.4 vs. 1.3) and 4% (2.4 vs. 2.5) for the chest and abdominopelvic areas, respectively (Brady et al., 2015).

The study identified limitations in the current use of DLP for effective dose calculations attributed to outdated methods for deriving the k-coefficients. Overall, the research illuminates a robust methodology for computing EICRP by leveraging patient size-specific dose estimates and making necessary adjustments to enhance EDLP accuracy (Brady et al., 2015).

In the study of Saltybaeva et al. (2014), the primary objective was to develop comprehensive dose-length product (DLP)-effective dose (ED) conversion coefficients (k) tables specifically tailored for the lower extremities. These tables aim to facilitate accurate ED calculations across various clinical scenarios where musculoskeletal CT and CT angiography protocols are commonly employed (Saltybaeva et al., 2014).

To achieve their goal, the researchers utilized a validated Monte Carlo simulation program to conduct dose estimations on standard phantoms. The study encompassed a range of tube voltages from 80 kV to 140 kV, in 20 kV intervals, focusing on specific lower-extremity examinations, including the hip (femur), knee, ankle, and CT angiography. The DLP values necessary for the calculations were obtained by multiplying the measured CT dose index values by the scan length (Saltybaeva et al., 2014).

The subsequent derivation of k values involved the division of the ED and DLP values. By averaging the DLP/ED coefficients corresponding to varied voltage settings, the researchers established a baseline understanding of how these values vary across different age groups and genders. Notably, the investigation revealed that phantom age and size significantly influenced the coefficients, whereas the kilovolt values showed minimal impact (Saltybaeva et al., 2014).

For instance, the study highlighted that for a baby phantom, the k values were notably different when compared to adult phantoms for the hip, knee, ankle, and CT angiography protocols. Additionally, a pertinent finding was the observed up to 20% variation in coefficients between male and female phantoms specifically for CT angiography (Saltybaeva et al., 2014).

Therefore, the conclusion drawn from this detailed investigation was the provision of vital DLP/ED conversion factors designed specifically for lower extremity applications. These coefficients are poised to significantly enhance the accuracy and

efficiency of estimating ED in routine clinical practice across various musculoskeletal CT and CT angiography scenarios (Saltybaeva et al., 2014).

Chapter 3: Materials and Methods

4.1. Patient selection

This study is a retrospective study for data collected from Al-Rahma Friends Society and Rafedia Surgical Hospital from January to October of 2024. The CT images of the examined patient have been collected from the Picture Archiving and Communication System (PACS). The patients were scanned using Philips Spectral CT 7500 (256 slice) and Philips Ingenuity multidetector CT scanner (64-slice) available at Al-Rahma Friends Society and Rafedia Surgical Hospital.

4.2. Patient classification

In this study, the targeted group was patients who underwent brain CT with and without age under 18 years old. Pediatric patients were selected randomly and categorized into four groups: neonates, infants, children, and adolescents as shown in Table 3.1.

Table 3.1: Pediatric groups with age window

Group	Age
Neonates	Birth up to 1 month
Infants	1 month to 2 years
Children	2 years to 12 years
Adolescence	12 years to 18 years

4.3. Data collection

Patient information like, age group, gender, and type of CT scan procedure was collected from the Rafidia and Al-Rahma hospitals PACS system which summarized in Table 3.2. The distribution of patient indication with age-related conditions was also collected, as shown in Table 3.3.

Table 3.2: Category of the age group based on number of cases, sex, and type of procedure used in CT.

Group	Number	Sex		Type of scan used	Number of patients based on the type of scan used
		Female	Male		
Neonates	2	-	2	Brain without contrast	2
Infants	44	16	28	Brain CT without contrast	43
				Brain CT with and without contrast	1
Children	68	26	42	Brain CT without contrast	62
				Brain with and without contrast	5
				Brain with contrast	1
Adolescence	26	3	23	Brain CT without contrast	20
				Brain CT with and without contrast	6

Table 3.3: The indications of patients who have been examined using a CT scan for each group type

Indication	Group type	Total
Congenital disease	Infant	1
Craniosynostosis	Infant	1

Delayed development	Children	1
Epilepsy	2 Children 2 Adolescence	4
Falling	1 Neonates 13 Infants 18 Children 2 Adolescence	34
Fever	1 Infants 2 Children	3
Hand tremor	1 Adolescence	1
Head size	Infants	1
Headache	2 Infants 8 Children 4 Adolescence	14
Headache + dizziness	Children	1
Hydrocephalus	1 Infant 1 Children	2
Hydrocephalus bleeding	Neonates	1
Injury of lower back	Children	1
Leg cramps	Infants	1
Extremity weakness	1 Infants 1 Children	2
Malignant neoplasm of brain	1 Children 1 Adolescence	2
Malignant neoplasm with pain or falling	Infants	2
Newborn health examination	Infants	1
Pain	14 Infants 21 Children 7 Adolescence	42
Extremity weakness + Headache	1 Adolescence	1
Skull enlargement	Infant	1
Trauma	3 Infants 11 Children 8 Adolescence	22
Vomiting	Infants	1

4.4. Brain CT Imaging Protocols of Pediatric

The radiation dose of the pediatric patients was assessed based on the brain CT examinations used. It was observed that there are different brain CT protocols for

pediatric patients used for each patient. In Rafidia surgical hospital, six protocols are available based on the age of the patient: (1) brain from childbirth to eighteen months without contrast, (2) brain from eighteen months to six years, (3) brain for pediatric patients who weights thirty to fifty kilograms, (4) brain without contrast media for adult patients, (5) brain computed tomography angiogram and (6) brain for pediatric patients who weights ninety to one hundred twenty kilograms.

The Tube voltage (keV) and (mAs) for each protocol are: 100 keV and 195 mAs, 100 keV and 180 mAs, 100 keV and 162 mAs, 120 keV and 350 mAs, 120 keV and 350 mAs, and 140 keV and 189 mAs, respectively. Al-Rahma Friends Society has five protocols for patients from birth to eighteen years old. Brain for patients who are (1) less than one year old, (2) brain from one to three years old, (3) brain from four to seven years old, (4) brain from eight to twelve years old, and (5) brain without contrast media. All of these protocols have the same 120 keV but different mAs, which are: 250, 250, 270, 290, and 320, respectively.

4.5. CT Radiation Dose Assessment

From the data that have been collected from Rafidia hospital, two main protocols have been used the most: (1) brain from 18 months to 6 years and (2) brain without contrast protocol for adult protocol. The experiment was done using these two protocols, which have different parameters. The first one has 100 keV and 180 mAs, while the second one has 120 keV and 350 mAs, which is under of adult brain CT protocol as shown in Table 3.4.

Table 3.4: Parameters of the brain from 18m-6y and the brain without protocol in Philips MDCT.

Parameter	Protocol	
	Brain from 18 months to 6 years without contrast	Brain without contrast for an adult
Chamber normalization factor	1	1
kVp	100	120
Exposure time in seconds	1	1
mAs	180	350
Pitch	0.399	0.399
Slice thickness	2 mm	3 mm

In contrast, in spectral CT, three protocols are the most used, two of them share the same keV and mAs: (1) Brain CT without contrast (adult protocol), (2) brain for those less than a year, and (3) brain from one to 3 years, as shown in Table 3.5.

Table 3.5: Protocols parameters of Spectral CT parameters.

Parameter	Protocol		
	Brain from 1-3 years without contrast	Brain less than 1 year without contrast	Brain without contrast for an adult
Chamber normalization factor	1	1	1
kVp	120	120	120
Exposure time in second	1	1	1
mAs	250	250	320
Pitch	0.4	0.296	0.4
Slice thickness	2 mm	2 mm	2 mm

For evaluating the radiation dose, the CTDI_v, total DLP, scan mode, tube current (mAs), and tube voltage (keV) for each scan were collected to compare the radiation dose related to the CT scan protocol.

4.6. CT Dose Measurements

In order to thoroughly assess the radiation exposure levels associated with pediatric brain CT scans, a team of researchers conducted an in-depth examination that involved extensive analysis of the system's CTDI value. Following this initial step, the researchers meticulously compared this value against empirical data derived from MDCT scans that utilized the same brand's 64-slice detector technology.

This comparative analysis allowed for a comprehensive evaluation of the radiation dosages involved in these imaging procedures. Moreover, all of these meticulous measurements were conducted on a specially designed head CT phantom specifically tailored to simulate the anatomy and size of pediatric patients' heads. By utilizing this phantom, researchers were able to accurately replicate the conditions of a pediatric CT scan, thereby ensuring precision and validity in their findings.

This detailed approach not only provided valuable insights into the radiation doses delivered during pediatric brain CT scans but also underscored the importance of employing standardized methods for assessing radiation exposure in pediatric populations. Ultimately, the researchers' thorough examination and careful analysis shed light on the critical issue of radiation safety in pediatric imaging, highlighting the need for ongoing research and advancements in technology to minimize risks and optimize patient care.

4.6.1. CTDI vol

CTDI vol was calculated by measuring the CTDI in peripheral (12, 3, 6, 9, 0” O'clock) and the center of the phantom. Then CTDIw was founded by the equation below. The final step was dividing CTDIw by the pitch of the used protocol.

$$CTDI_w = \frac{1}{3} CTDI_{100, \text{center}} + \frac{2}{3} CTDI_{100, \text{peripheral}} \dots (\text{Arfat et al., 2024})$$

$$CTDI_v = CTDI_w / \text{pitch} \dots (\text{Arfat et al., 2024})$$

4.6.2. DLP

DLP was calculated by multiplying the CTDI vol by the scan length in cm.

$$DLP = CTDI \text{ vol (mGy)} \times \text{scan length (cm)} \dots (\text{Arfat et al., 2024})$$

4.6.3. Effective dose

Finally, the effective dose was found by multiplying DLP (mGy) by the k factor. The k factor is inconstant because of different variables like age, BMI and etc.

4.7. Phantom Construction

Images from CT scans of 140 patients in Rafidia hospital and Al-Rahma Friends Society were evaluated to assess the average normal dimensions of size of head of targeted age to create a pediatric head phantom. The midsagittal plane was used to measure the height of the skull, and the coronal plane was used to measure the diameter. It was confirmed in the axial plane: the long axis from anterior to posterior and the short axis from left to right. The soft tissue material used to create the phantom was based on 40% water, 20% sodium hydroxide, and 50% olive oil. The bone material's content in the bone region was 26% calcium sulfate and 74% distilled water (Abdalqader et al., 2024).

The bone material and olive oil mixture were placed into a mold that simulated the size measured previously. A hole was opened in the center and 4 in the peripheral area to measure the CTDIvol in the phantom and compare it with the data available at the system. Pencil CT chamber (Raysafe x2) was used for all measurements. The average dose was

measured for each point in the center of the phantom and in the peripheral at 12, 3, 6, and 9 o'clock.



Figure 3.1: Pediatric head phantom during scanning

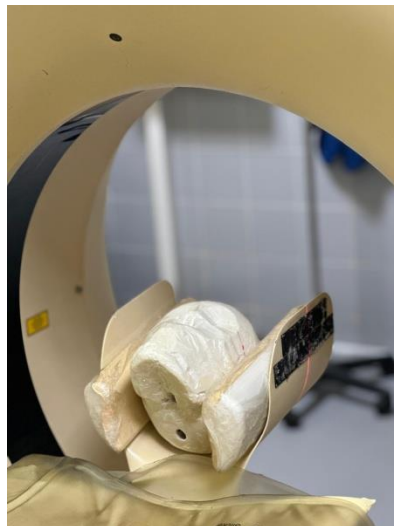


Figure 3.2: Pediatric head phantom showing the holes in the phantom

4.8. Statistical Analysis Plan

The data were analysed using SPSS version 26. Descriptive statistics were used to summarize dose metrics (mean, median, SD, range) for each protocol and scanner, stratified by age/weight groups (e.g., <1 yr, 1–5 yr, 5–10 yr). For comparative analysis, independent t-tests were used to compare doses between Spectral CT and MSCT scanners. Correlation was used to assess the relationship between patient brain measures and dose. Measure validation was analysed using paired t-tests to compare measured doses against clinical averages. A p-value of less than 0.05 was considered statistically significant.

Chapter 4: Results

This chapter presents the results of a comprehensive evaluation of radiation dose parameters: CTDI vol, DLP, and effective dose among pediatric patients who underwent head CT scans. The analysis assesses variation in dose metrics across CT scanner types (Philips MSCT and Spectral CT), different estimation methods (achieved localizer, nominal localizer, and phantom-based), age categories, and patient size.

5.1. Descriptive Statistics of Study Population Characteristics

A total of 140 pediatric patients underwent head CT examinations across two different scanner types. Of these, 60% ($n = 84$) scans were performed using the Philips MSCT scanner, while the remaining 56 (40%, $n = 56$) utilized the Spectral CT system. The most frequent clinical indication for imaging was unspecified pain (30%), followed by falls (24.3%), trauma (15.7%), headache (10%), and epilepsy (2.9%). Less common indications included congenital anomalies, hydrocephalus, and vomiting (each representing 0.7%).

The majority of patients (90.7%) underwent non-contrast brain CT, while 9.3% had both contrast and non-contrast imaging. The sample consisted of 67.9% ($n = 95$) males and 32.1% ($n = 45$) females. In terms of age distribution, children aged 1–5 years accounted for the largest group (39.3%), followed by 6–10 years (21.4%), 11–15 years (19.3%), less than 1 year (14.3%), and 16–20 years (5.7%) (Table 4.1).

Table 4.1: Patient and Scan Characteristics (N = 140)

Variable	% (n)
Scanner Type	
Philips MSCT	60 (84)
Spectral CT	40 (56)
Indication	
Pain	30 (42)
Falling	24.3 (34)
Trauma	15.7 (22)
Headache	10.0 (14)
Others ($\leq 2.9\%$ each) *	20 (28)
Procedure	
Brain CT without contrast	90.7 (127)
Brain CT with and without	9.3 (13)
Gender	
Male	67.9 (95)
Female	32.1 (45)
Age Category	
<1 year	14.3 (20)
1–5 years	39.3 (55)
6–10 years	21.4 (30)
11–15 years	19.3 (27)
16–20 years	5.7 (8)

*Other indications include: Congenital disease, craniosynostosis, epilepsy, fever, hydrocephalus, malignancies, vomiting, and similar low-frequency reasons.

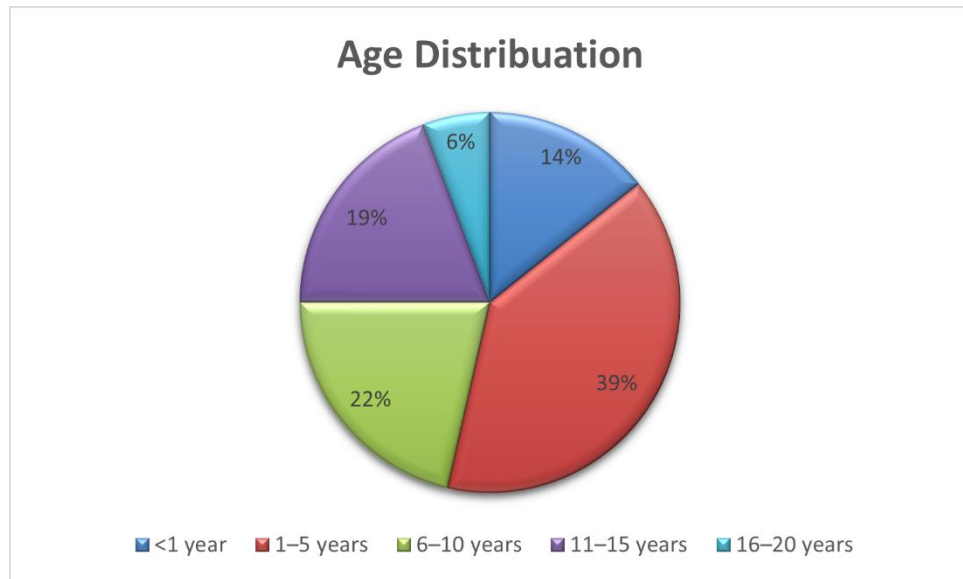


Figure 4.1: Age distribution of pediatric brain patients

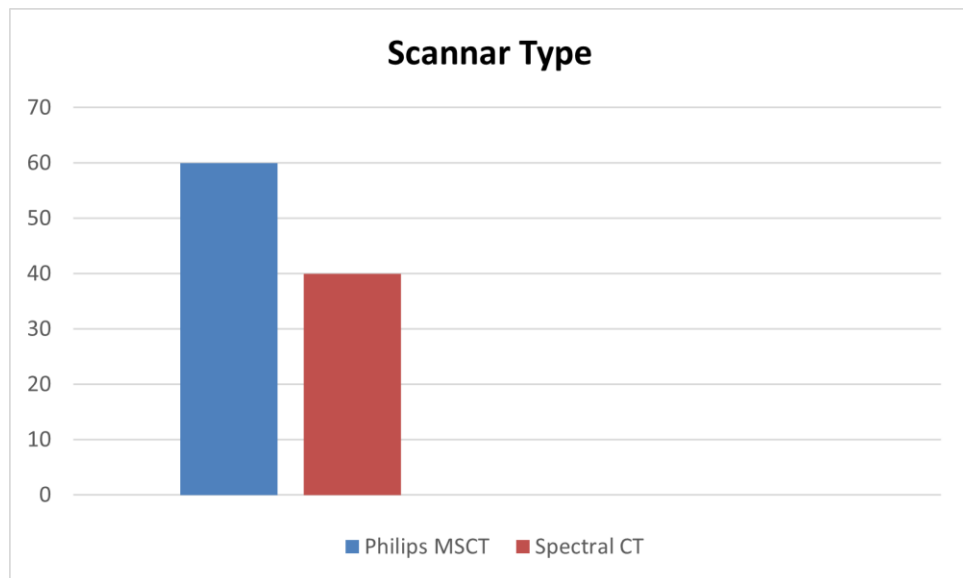


Figure 4.2: The distribution of population sample among the scanner type

5.2. Radiation Dose Descriptive Statistics

Among all patients, the mean CTDI_{vol} was 33.97 mGy (SD = 16.11), with a range of 8.40–58.10 mGy. The corresponding DLP based on achieved localizer data averaged 810.61 mGy·cm (SD = 427.38), and the effective dose was 3.96 mSv (SD = 2.10). When doses were recalculated using nominal localizer lengths, the DLP decreased to 459.73

mGy·cm (SD = 233.94), and the effective dose reduced to 2.23 mSv (SD = 1.10). Phantom-based estimations resulted in a higher mean CTDIvol of 41.37 mGy (SD = 21.37), a DLP of 528.78 mGy·cm (SD = 274.17), and an effective dose of 3.54 mSv (SD = 1.84).

Table 4.2: CT dose parameters based on different estimation methods (N = 140)

Dose Parameter	Mean	SD	Min	Max
Achieved localizer				
Estimated CTDIvol (mGy)	33.97	16.11	8.4	58.1
DLP (mGy·cm)	810.61	427.38	192	2243
Effective dose (mSv)	3.96	2.1	0.88	10.92
Nominal localizer				
Estimated CTDIvol (mGy)	33.97	16.11	8.4	58.1
DLP (mGy·cm)	459.73	233.94	104.34	871.5
Effective dose (mSv)	2.23	1.1	0.45	6.68
Phantom-based				
Estimated CTDIvol (mGy)	41.37	21.37	23.98	67.45
DLP (mGy·cm)	528.78	274.17	305.72	863.36
Effective dose (mSv)	3.54	1.84	2.04	5.78

5.3. Age-Based Dose Variation

An age-stratified analysis indicated a progressive increase in radiation exposure with age. The youngest group (<1 year) showed the lowest DLP values (M = 497.93 mGy·cm), while the 16–20 age group showed the highest (M = 1265.61 mGy·cm). Likewise, nominal DLP increased from 266.13 mGy·cm (<1 year) to 681.44 mGy·cm (16–20 years). Effective dose trends were less linear: the highest effective dose occurred in the <1 year group (M = 5.47 mSv), decreased in mid-age groups (6–10: M = 3.33 mSv), and rose again in the 16–20 group (M = 4.04 mSv). This pattern reveals the interaction between body size, scan length, and parameters used, such as keV, mAs, pitch, and slice thickness.

CTDIvol values displayed a consistent increase with age, from 24.26 mGy in the youngest group to 46.83 mGy in the oldest. The distribution of values varied significantly, particularly in younger and older patients, highlighting the need for individualized protocol optimization.

5.4. Radiation Dose Comparison by Scanner Type

To evaluate how scanner type influences radiation exposure in pediatric head CT, an independent samples *t*-test was performed to compare radiation dose parameters between two different CT scanner types: Philips MSCT and Spectral CT. The analysis revealed that the CTDIvol was significantly higher for the Spectral CT scanner compared to the Philips MSCT scanner ($t(138) = 12.6, p < .001$).

This difference suggests that patients scanned on the Spectral CT are routinely exposed to almost double the radiation dose per volume compared to those scanned on the Philips MSCT. Similarly, the DLP based on achieved localizer length was substantially greater in the Spectral CT group than in the Philips MSCT group, with this difference also reaching statistical significance ($t(138) = 7.41, p < .001$). This indicates that Spectral CT scans tend to involve not only higher output per unit area but also greater total radiation exposure per scan.

The effective dose, which estimates the potential biological effect of radiation exposure, followed the same pattern. Patients examined using Spectral CT received a significantly higher effective dose compared to those scanned with Philips MSCT ($t(138) = 5.06, p < .001$). Additionally, the nominal CTDIvol for Spectral CT remained significantly higher than that of Philips MSCT, and both nominal DLP and nominal effective dose followed similar patterns, with Spectral CT consistently yielding significantly higher values (all $p < .001$). These findings highlight the importance of considering scanner type as a major determinant of radiation exposure, particularly in sensitive pediatric populations. The results strongly indicate that the Spectral CT scanner, while potentially offering improved image quality or spectral imaging advantages, requires careful optimization to manage the associated increase in radiation dose (Table 4.3).

Table 4.3: Radiation Dose Comparison by Scanner Type

Dose Parameter	Philips MSCT Mean \pm SD	Spectral CT Mean \pm SD	p-value
Achieved Localizer			
Estimated CTDIvol (mGy)	24.46 \pm 13.56	48.24 \pm 5.72	< .001
DLP (mGy·cm)	612.95 \pm 419.24	1107.11 \pm 217.25	< .001
Effective Dose (mSv)	3.31 \pm 2.03	4.94 \pm 1.81	< .001
Nominal Localizer			
Estimated CTDIvol (mGy)	24.46 \pm 13.56	48.24 \pm 5.72	< .001
DLP (mGy·cm)	332.84 \pm 202.10	650.07 \pm 123.24	< .001
Effective Dose (mSv)	1.82 \pm 0.98	2.86 \pm 0.97	< .001
Phantom based			
CTDIvol (mGy)	23.98 \pm 0.00	67.45 \pm 0.00	< .001
DLP (mGy·cm)	305.72 \pm 0.00	863.36 \pm 0.00	< .001
Effective Dose (mSv)	2.04 \pm 0.00	5.78 \pm 0.00	< .001

5.5. Influence of Patient Size on Radiation Dose

To further explore the impact of individual patient characteristics on radiation exposure, correlations were calculated between body size parameters (height, long axis, and short axis) and radiation dose estimates. Results revealed a moderate, statistically significant positive correlation between patient height and CTDIvol ($r = 0.356$, $p < .001$), as well as between height and nominal DLP ($r = 0.509$, $p < .001$).

This suggests that taller patients tended to receive higher radiation doses, likely due to protocol adjustments based on size or anatomy. Similarly, statistically significant positive correlations were found with long axis and short axis measurements, which also demonstrated moderate correlations with both CTDIvol and nominal DLP ($r \approx 0.37 - 0.50$, $p < .001$). These relations support the use of patient-specific metrics when tailoring scan parameters to minimize unnecessary radiation exposure.

Interestingly, the relationship between body size and nominal effective dose was not statistically significant. For example, the correlation between height and effective dose was relatively weak and non-significant ($r = 0.162$, $p = .058$). This lack of association suggests that while scan length and radiation output may vary with body size, the calculated effective dose (which incorporates age and tissue sensitivity) may be less directly influenced by linear body dimensions. This underscores the complexity of effective dose estimation and suggests a potential need for more advanced methods to accurately account for patient variability.

5.6. Comparison of Radiation Dose Estimation Methods

Given the critical importance of accurate dose estimation, the study compared three different calculation methods: achieved localizer-based measurements, nominal localizer-based approximations, and estimates derived from age-specific phantoms. Substantial variation was observed across these methods, which has important implications for clinical practice and dose monitoring protocols.

Paired t-tests were conducted to evaluate systematic differences between estimation methods. The results revealed statistically significant differences across all pairwise comparisons. CTDI_{vol} estimates were significantly higher when using phantom-based protocols than those based on nominal localizer values ($t(140) = 8.11$, $p < .001$).

For DLP, the achieved localizer method produced the highest values, significantly exceeding both nominal DLP and phantom-derived DLP; all differences were statistically significant ($p < .001$). Similarly, the effective dose was highest using the achieved localizer method, followed by phantom-based estimates, and lowest with nominal calculations.

All differences were statistically significant ($p < .001$). These results emphasize how different assumptions and simplifications in dose estimation (such as fixed scan lengths or age-based look-up values) can lead to substantial under- or overestimation of patient dose.

To further evaluate these differences while accounting for within-subject variability, a repeated-measures General Linear Model (GLM) was employed. For patients scanned with the Philips MSCT, there was no significant difference in CTDIvol across estimation methods ($F(1, 83) = 0.105$, $p = .747$), suggesting consistency in volume dose across methods for this scanner. However, highly significant differences were found for both DLP ($F(2, 166) = 53.37$, $p < .001$, Partial $\eta^2 = 0.391$) and effective dose ($F(2, 166) = 51.94$, $p < .001$, Partial $\eta^2 = 0.385$). These effect sizes indicate that nearly 40% of the variance in dose estimates could be attributed to the estimation method alone.

When the entire sample (all scanners) was included in the model, the differences across methods became even more pronounced. For CTDIvol, the method effect was highly significant ($F(2, 110) = 630.44$, $p < .001$, Partial $\eta^2 = 0.920$), with similar patterns observed for DLP ($F(2, 110) = 219.85$, $p < .001$, Partial $\eta^2 = 0.800$) and effective dose ($F(2, 110) = 144.99$, $p < .001$, Partial $\eta^2 = 0.725$). These large effect sizes reinforce the substantial impact that the estimation approach has on reported dose values and further support the use of achieved localizer-based calculations for more accurate dose monitoring.

5.7. Summary of Key Findings

This study reveals significant variability in pediatric head CT radiation doses based on scanner type, patient age, body size, and dose estimation method. Notably:

- Spectral CT scanners deliver significantly higher radiation doses than Philips MSCT, across all dose metrics.
- Radiation dose increases with age and body size, but effective dose does not scale linearly with body dimensions.
- Achieved localizer-based methods consistently produce the highest—and potentially most accurate—dose estimates, compared to nominal and phantom-based calculations.
- Dose estimation method accounts for a substantial proportion of the variability in reported DLP and effective dose, with clinical implications for dose tracking, benchmarking, and optimization efforts.

These findings highlight the need for consistent, scanner-specific protocols and underscore the value of using achieved scan parameters for dose evaluation in pediatric populations. Ensuring accurate dose estimation is especially important for reducing unnecessary radiation exposure in young patients, who are more vulnerable to long-term radiation effects.

Chapter Five: Discussion

This part emphasizes the critical importance of a newly available medical imaging gadget in the West Bank called the spectral CT scan. The device offers several key benefits, most notably a dramatic reduction in the radiation dose delivered to patients. This is a significant advancement, considering the documented impact of inappropriate tube voltage adjustment on image quality.

The major goal of this study was to characterize the brain structure and characteristics of pediatric patients aged 0 to 18 years. This involved a comparison of radiation exposure levels between two different CT scanning techniques: dual-detector spectral CT and MDCT. The research likely involved acquiring brain CT scans from a cohort of pediatric patients across the specified age range using both dual-detector spectral CT and MDCT. Subsequently, the acquired image data would have been analysed to assess and compare the radiation dose received by the patients in each group.

The ultimate aim was to determine whether one technique offered a significant advantage over the other in terms of radiation exposure while maintaining adequate image quality for pediatric brain imaging. This information would be crucial for optimizing clinical practice and minimizing radiation risk to young patients.

TBI is one of the most common causes of dysfunction and death among children. The diagnosis often requires a CT scan to assess the extent of the damage. The severity of TBI can range from mild concussion to severe, life-threatening injuries. Prompt medical attention, including rapid assessment and stabilization, is crucial in managing TBI in children to minimize long-term neurological deficits and improve survival rates. The long-term consequences of TBI can include cognitive impairments, physical disabilities, and behavioural changes, highlighting the importance of early intervention and ongoing support (Araki et al., 2017).

Nervous system cancers represent the second most prevalent type of tumor in pediatric patients, following leukaemia, highlighting the significant number of childhood

cancer cases. Brain tumors, comprising approximately 15% of all pediatric cancers, present unique challenges due to their complex nature and the delicate structures within the brain (Shaari et al., 2021). Children's brain cancer cases encompass a variety of forms, with embryonal tumors and brainstem gliomas being prevalent among them. Additionally, rare brain cancers like choroid plexus tumors and schwannoma, known for their benign characteristics, highlight the diverse tumor forms encountered in young patients (Shaari et al., 2021).

MRI plays a crucial role in comprehensive neuroimaging examinations, offering advantages over CT and ultrasound in detecting certain brain abnormalities. While CT and ultrasound are preferred for identifying calcifications, MRI's superior soft tissue contrast allows for the easier detection of subtle but critical neurological issues that may be missed by the other modalities (Smiljkovic et al., 2019).

Specifically, MRI excels at visualizing and characterizing conditions such as cerebellar hypoplasia (incomplete development of the cerebellum), gyration anomalies (abnormalities in the brain's folding patterns), and various types of white matter changes. These conditions, often indicative of underlying neurological disorders, can be challenging to fully assess using CT or ultrasound alone. Therefore, MRI serves as a valuable complementary imaging technique, providing a more complete picture of brain structure and potential pathologies (Smiljkovic et al., 2019).

Conventional CT techniques have undergone significant advancements with the emergence of detector-based SDCT. Unlike traditional CT scanners, SDCT utilizes dual-layer detectors to simultaneously acquire both low- and high-energy X-ray projection data (Ananthakrishnan et al., 2017).

This dual-energy acquisition capability enables the generation of several image types through a process called projection-space decomposition. These include standard polyenergetic images (similar to those from conventional CT), spectral basis images

representing the underlying spectral components of the X-ray attenuation, and material-specific images (Ananthakrishnan et al., 2017).

Examples of material-specific images include iodine-only images (useful for visualizing contrast enhancement), virtual non-contrast images (simulating an image without intravenous contrast administration), and effective atomic number images (providing information about tissue composition). The specific image type generated can be tailored to meet the needs of various clinical applications (Ananthakrishnan et al., 2017).

A key advantage of SDCT is its flexibility in post-processing. The effective tube voltage can be modified after image acquisition and during the image reconstruction process. This post-processing flexibility allows for optimization of image quality parameters, such as noise reduction and contrast enhancement, without the need for repeat scans. This feature is particularly beneficial for maximizing diagnostic information from a single scan, minimizing radiation dose, and improving workflow efficiency (Ananthakrishnan et al., 2017).

SDCT leverages the differing attenuation coefficients of various tissues at different X-ray energies to enhance image contrast and diagnostic accuracy. Unlike conventional single-energy CT, SDCT employs multiple energy levels during data acquisition. This dual-energy or even multi-energy approach leads to the generation of a significantly larger dataset compared to standard CT scans. The increased information content allows for improved tissue characterization, facilitating the differentiation between materials with similar densities but different compositions (Nagayama et al., 2021).

Tube voltage is a key factor in controlling radiation dose during imaging procedures. The relationship between tube voltage and radiation dose is linear, meaning that as one increases, the other increases proportionally. When the tube voltage is raised, the machine emits more energy, resulting in a higher dose of radiation reaching the patient. Conversely, lowering the tube voltage reduces the radiation exposure significantly (Feldle et al., 2024).

If the tube voltage is lowered further, from 120 kVp down to 80 kVp, the radiation dose can decrease by about 65 percent. That's a substantial decrease, which can greatly reduce the risk of radiation-related side effects or long-term health issues, especially for sensitive populations like children or patients needing multiple scans. These relationships are well understood by radiologists and medical physicists, who often use this knowledge to optimize scanning protocols (Feldle et al., 2024).

CTDI and DLP are fundamental metrics used in the regulation and evaluation of radiation exposure levels. The CTDI focuses on assessing the amount of radiation received from a single slice during a scan, serving as a gauge of the scanner's radiation output in standardized scenarios. On the other hand, the DLP provides a comprehensive measurement, taking into account the total radiation dosage across the length of the scanned area. Both CTDI and DLP play an essential role in determining and managing the radiation dose administered during CT scans, ensuring that exposure stays within safe limits (Arfat et al., 2024).

The CTDI plays a critical role in quantifying the radiation dosage output of a CT scanner, reflecting the dose delivered per slice during a scan. Originally, measurements such as CTDI₁₀₀ and CTDI_w were employed, with CTDI₁₀₀ focusing on the dosage from a single axial CT slice using a 100mm ionization chamber within a phantom. (Arfat et al., 2024).

While these parameters are pivotal in setting exposure reference values, it is important to note that they do not directly correlate with the actual radiation dose received by the patient. The diagnostic reference levels (DRLs) are crucial in overseeing and controlling patient exposure, thereby facilitating the delivery of precise therapeutic interventions during CT examinations. By adhering to established DRLs, healthcare providers can strike a balance between acquiring detailed imaging information required

for accurate diagnoses and minimizing the potential risks associated with radiation exposure, ensuring patient safety and quality healthcare outcomes (Arfat et al., 2024).

5.1. Descriptive Statistics of Study Population Characteristics

The result indicates that the highest percentage clinical indication of pediatric brain imaging is unspecified pain 30% and the lowest indication was epilepsy 2.5%. The analysis indicates that pediatric brain CT without contrast was more than with contrast, 90.7% and 9.3%, respectively. Another finding for population characterization was that the number of male patients, 67.9% was higher than female patients, 32.1%.

The last result shows that the largest group was from 1-5 years old, 39.3% and the smallest group was from 16-20 years. These results are consistent with a previous study by Haghghi et al. (2014), which proved that the number of pediatric brain CTs of male patients is higher than that for female patients, with 50.3% for male (Haghghi et al., 2014b).

5.2. Radiation Dose Descriptive Statistics

The comparison between different estimation methods for CTDI vol (mGy), DLP (mGy/cm), and effective dose (mSv). The mean and SD for CTDI vol were the lowest for achieved and nominal localizer (33.97 ± 16.11), the mean for CTDI vol for phantom-based was higher (41.37 ± 21.37). The highest value for mean DLP was for the achieved localizer (810.61 ± 427.38), and the lowest value was for the nominal localizer. The last CT dose parameter was the effective dose, that result shows the highest value was from the achieved localizer (3.96 ± 2.1) and the lowest value was in the nominal localizer (2.23 ± 1.1).

This discrepancy in the radiation dose could be attributed to the size of the localizer used. The mean of DLP for the achieved localizer was the highest because the length of the scan is longer in the achieved localizer. This finding is in line with results obtained by Badawy et al (2015) and Saltybaeva et al. (2014), who confirmed that even a 6 cm

over scan length could increase the CTDI vol by 1 mSv and lead to an increase in DLP (Badawy et al., 2015; Saltybaeva et al., 2014).

On the other hand, the reason that made CTDIvol based on phantom is higher because the majority of the CT scans available at West Bank are not frequently calibrated, which explains the high level of radiation dose in the phantom, which is the real dose. The same point was noted by Seibert et al (2014), who concluded that a measure of radiation dose in CT scans is significantly influenced by several factors, leading to potential inaccuracies in dose estimation.

These factors include the specific acquisition parameters used during the scan (such as tube current, voltage, and slice thickness) and the diameter of the calibration phantom used in the measurement. Variations in these parameters can result in either an overestimation or underestimation of the actual radiation dose received by the patient (Seibert et al., 2014).

This discrepancy is particularly pronounced in pediatric examinations. When comparing CTDIvol measurements from different manufacturers, significant differences may arise if the calibration is performed using different phantom diameters. The use of a 32 cm PMMA (polymethyl methacrylate) phantom versus a 16 cm PMMA phantom can yield vastly different CTDIvol values, thereby complicating accurate dose comparisons and potentially obscuring the actual dose delivered to the child patient. This is because CTDI vol, while providing a standardized metric, isn't directly proportional to the size of the organ being scanned in all situations.

The relationship is complex and influenced by the aforementioned parameters, making direct size proportionality an oversimplification. Accurate dose assessment in pediatrics requires careful consideration of these variables and potentially more sophisticated dosimetry methods (Inoue et al., 2022; Seibert et al., 2014).

The last parameter was the mean effective dose for the achieved localizer was the highest value, and the lowest was in the nominal localizer, and this was affected by the DLP value; the relation between effective dose and DLP is proportional (Brady et al., 2015).

5.3. Age based on Dose Variation

There was a correlation between age and the three CT dose parameters, which are DLP, effective dose, and CTDI vol. Firstly, the number shows that the youngest group (<1 year) has the lowest value of DLP (M = 497.93 mGy·cm). The oldest group (16-20 years) shows the highest value of DLP (Mean = 1265.61 mGy/cm). This shows there is a significant correlation between the radiation dose and the age of the scanned patient.

Unlike the second parameter, the effective dose, which is the highest in the youngest age (<1 year) (Mean = 5.47 mSv) and lowest in the mild-age group (6–10: Mean = 3.33 mSv), so that the correlation is inversely proportional. The correlation of CTDI vol with age is directly proportional, like the DLP, from 24.26 mGy in the youngest group to 46.83 mGy in the oldest. The reason that could explain this is that the DLP increases with age, unlike the effective dose decrease, so the correlation between age and effective dose is inversely proportional. Therefore, the youngest age has the highest effective dose (Mean = 5.47 mSv) compared to the oldest age (Inoue et al., 2022).

While with age increasing, the CTDI vol and DLP increase (Kharita et al., 2020), which correspond with results in the study, CTDI vol 24.26 mGy in the youngest group to 46.83 mGy in the oldest.

5.4. Radiation Dose Comparison by Scanner Type

There was a variation in radiation dose in comparison between the Philips MSCT system and the spectral CT scanner; the comparison between the two devices was for CTDIvol, DLP, and effective dose in the achieved localizer, nominal localizer, and phantom. The results showed that all values of spectral CT were higher than those of Philips MSCT.

In general, achieved localizer approximately have the higher values when compared to nominal localizer and phantom based in the two devices: in Spectral CT only the DLP is the highest (1107.11 ± 217.25) and it is higher than in Philips MSCT (612.95 ± 419.24), the effective dose is the highest in the phantom based in Spectral CT (5.78 ± 0.00), the Spectral has higher values than MSCT Philips (5.78 ± 0.00 , 2.04 ± 0.00). The CTDI vol of Spectral CT in the phantom was the highest value (67.45 ± 0.00).

The nominal localizer in spectral CT has the lowest values of mean DLP and effective dose (650.07 ± 123.24 , 2.86 ± 0.97), respectively, in compared to achieved localizer and phantom based, however in Philips MSCT, only the effective dose is the lowest (1.82 ± 0.98), however the Spectral CT values of DLP and effective dose of nominal localizer are higher than the ones in Philips MSCT, DLP (650.07 ± 123.24 , 332.84 ± 202.10), effective dose (2.86 ± 0.97 , 1.82 ± 0.98).

The high value DLP in the achieved localizer for Spectral CT is due to the high value of CTDIvol, which is the CTDIvol multiplied by the scan length (Arfat et al., 2024). The results demonstrated that the mean of CTDI vol for Spectral CT is larger. Therefore, the DLP value obtained, and this value will increase as the size of the field increases, in addition to the scanning parameters used in the scan, is another factor that could affect these values

Relating to the scanning parameters used, the Spectral CT in Alrahma hospital has higher exposure parameters compared to Philips MSCT in a screened pediatric patient. Where the range of scanning parameters used in spectral CT was 120 keV, 450-250 mAs, and approximately 0.4 pitch. The reason for using this high value is attributed to that some radiographers use adult protocols on pediatric patients, which contributes to increasing the radiation dose of pediatric patients (CTDI vol, DLP, and effective dose). A study of Doerner et al. (2017) confirmed that using low kVp of Dual-layer spectral CT can reduce patient dose with better image quality (Doerner et al., 2017).

So, that's the main reason that made the CTDIvol, DLP, and effective dose higher in the Spectral CT compared to the Philips MSCT system. On the contrary, Philips MSCT in Rafidia hospital has been using pediatric protocol with 100-120 kV, 180-320 mAs, and 0.4 pitch. The slice thickness is approximately the same in the two devices, so it does not contribute to the dose differentiation. Since the keV is proportional to CTDI vol, Spectral CT delivers more radiation dose (high CTDI vol and DLP) than Philips MSCT.

These results did not fit with the hypothesis, because the CTDI vol, DLP, and effective dose are higher in spectral CT than Philips MSCT, and that is because the exposure parameters are inappropriate to the group age for pediatric brain patients.

A study of Spampinato et al. (2018) concluded that the dose can be reduced in the pediatric head protocol to CTDI vol (20 mGy) for infants whom less than one year and (28mGy) CTDI vol for children from one to nine years old and giving images that were declared of diagnostic quality by adjusting the pediatric head protocol to reduce the patient dose (Spampinato et al., 2018)

The interplay of these parameters and variables underscores the complexity of accurately determining the patient's absorbed dose. Inconsistencies in any of these factors can lead to either an overestimation (potentially causing unnecessary patient anxiety or prompting unwarranted radiation safety interventions) or an underestimation (potentially overlooking the need for dose optimization strategies). Standardization protocols and careful attention to detail during both scan acquisition and post-processing are essential for minimizing dose calculation errors and ensuring patient safety (Seibert et al., 2014).

The study found a moderate, statistically significant positive connection between patient height and CTDIvol ($r = 0.356$) and nominal DLP ($r = 0.509$). This shows that taller individuals received larger radiation doses, most likely as a result of protocol changes depending on size or anatomy. Long and short axis measures showed statistically significant positive associations, as well as moderate correlations with CTDIvol and

nominal DLP ($r \approx 0.37 - 0.50$). These findings support the use of patient-specific measurements to modify scan parameters and reduce excessive radiation exposure.

For Spectral CT, Phantom-based methods resulted in much larger CTDIvol estimates than those based on nominal localizer values. For DLP, the obtained localizer approach produced the greatest values, greatly exceeding both nominal DLP and phantom-derived DLP.

For patients scanned with the Philips MSCT, there was no significant variation in CTDIvol between estimating methods, indicating that volume dosage is consistent across approaches for this scanner. However, there were highly significant variations for both DLP and effective dosage. According to these impact sizes, the estimating method alone accounts for roughly 40% of the range in dosage estimations.

When the whole sample (all scanners) was included in the model. These considerable effect sizes demonstrate the significant impact of the estimating approach on reported dose values and advocate the use of accomplished localizer-based calculations for more accurate dose monitoring.

5.5. Conclusion

This study investigates the variability in pediatric head CT radiation doses, revealing significant differences based on scanner type, patient age, and dose estimation method. The research demonstrates that spectral CT scanners consistently deliver substantially higher radiation doses than Philips MSCT scanners across all measured dose metrics (e.g., CTDIvol, DLP, effective dose). Furthermore, the study found a positive correlation between radiation dose and both patient age and body size. However, this relationship is not linear; effective dose does not scale proportionally with increasing body dimensions.

A key finding highlights the superior accuracy of localizer-based dose estimation methods compared to nominal and phantom-based calculations. Localizer-based methods consistently yielded the highest dose estimates, suggesting they may provide the most

accurate representation of actual radiation exposure. The choice of dose estimation method itself accounts for a considerable portion of the variability in reported dose metrics (DLP and effective dose), with important implications for accurate dose tracking, benchmarking, and optimization strategies in clinical practice.

These findings emphasize the critical need for consistent, scanner-specific protocols for pediatric head CT scans. The study strongly advocates for utilizing achieved scan parameters (as opposed to nominal or phantom-based estimates) for accurate dose evaluation in this vulnerable population. The increased susceptibility of young patients to long-term radiation effects underscores the paramount importance of minimizing unnecessary radiation exposure through precise dose estimation and optimized scanning techniques. Future research should focus on developing and implementing standardized protocols to reduce variability and ensure consistent, accurate dose reporting across different scanners and institutions.

5.6. Recommendation

The results of this study strongly suggest that when evaluating young patients with known brain abnormalities, medical professionals should give top priority to choosing the best imaging device. Both the appropriate age procedure and the radiation dose parameters, such as tube voltage and tube current, must be considered.

Although this study shows that the Spectral CT delivers more radiation dose than MSCT, it is proven that the improper protocol for the patient causes this problem. And to solve this dilemma, it is suggested to optimise the exposure parameters and choose the proper protocol depending on the patient's age. This reduction in radiation exposure is a vital consideration in the imaging of this patient population, as it helps to minimize the risk of radiation-related complications while still providing high-quality diagnostic imaging.

5.7. Strength of the Study

In order to evaluate important indicators—the radiation dose administered by two distinct CT imaging devices and the efficacy of a novel spectral detector integrated within a new CT device—this study critically examined patients with a variety of indications of pediatric brain pathology.

This study's retrospective design significantly reduced the possibility of bias. The participating research institutes supplied the necessary data, and the researchers' cooperation with their personnel greatly aided in the collection of precise and trustworthy data.

This study emphasized how important it is to reduce the possible negative consequences of radiation exposure on patients. The results support the development of imaging technologies to enhance patient safety and diagnostic precision in young brain health evaluations.

This study has several limitations. First, miscalibration of devices led to inaccurate values, particularly for CTDI_{vol}. Inappropriate exposure parameters used in the spectral pediatric brain protocol, which failed to account for patient age, further compromised the accuracy of the results.

A second limitation stems from the lack of consideration for other potential brain pathologies. The study did not account for the presence of other conditions, such as brain cancers or masses, which might influence the selection of an ideal protocol and the minimization of radiation dose. Ideally, the scanning procedure would have been tailored to the specific pathology of each patient. However, this was not feasible due to the fact that the majority of patients were examined incidentally, rather than for targeted investigation.

Finally, the findings were not compared to standard diagnostic images generated by other SDCT scanning systems, preventing a comprehensive evaluation of the results.

5.9. Future work

Several intriguing research areas and prospective future studies are underway to further investigate the innovative SDCT device's use in the identification and characterization of numerous pediatric brain illnesses. These areas of research could greatly improve our understanding and implementation of this technology.

The iterative model reconstruction in conjunction with SDCT is great promise for imaging the brains of young patients with a variety of disorders. When evaluating pediatric patients' brains, this imaging method can be quite helpful. This method must be evaluated in a future study.

A thorough analysis comparing traditional computed tomography (CT) procedures to SDCT is required. This study should evaluate crucial variables such as SDCT's sensitivity, specificity, and overall diagnostic efficacy. Researchers will gain a better understanding of how SDCT improves diagnostic accuracy and reduces radiation dosage for pediatric brain disorders by rigorously analyzing its strengths and weaknesses in comparison to standard CT. This comparative study should include a diverse cohort of individuals with various types of pediatric brain disorders (e.g., hydrocephalus, brain tumors, infections) to ensure reliable and generalizable results. The comparison should also consider factors such as image quality, scan time, and cost-effectiveness.

Longitudinal studies are required to monitor patients over extended periods (e.g., 1-5 years or more), tracking disease progression and treatment response. This is particularly beneficial for high-risk populations (e.g., premature infants, those with genetic predispositions) where routine screening protocols using SDCT could be developed and implemented into clinical practice to facilitate early intervention and improved management of pediatric brain diseases. These studies will provide valuable data on the long-term effects of SDCT and its impact on patient outcomes. Specific outcome measures should be defined beforehand, such as changes in clinical symptoms, cognitive development, and quality of life.

It is also critical to investigate advances in imaging technology that may further enhance SDCT's capabilities. This includes exploring the use of sophisticated image processing techniques (e.g., noise reduction, artifact correction), artificial intelligence (AI) algorithms for automated image analysis and diagnosis, and other novel contrast agents that might improve image contrast and specificity. The integration of AI could potentially automate the detection of subtle abnormalities, improving diagnostic accuracy and efficiency.

Research into the development of specialized SDCT protocols optimized for different pediatric age groups and brain pathologies is also warranted. Finally, studies assessing the cost-effectiveness of SDCT compared to current imaging modalities are needed to guide resource allocation and clinical decision-making.

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Appendices

Appendix 1: IRB approval

Arab American University
Institutional Review Board - Ramallah



الجامعة العربية الأمريكية
مجلس أخلاقيات البحث العلمي - رام الله

IRB Approval Letter

Study Title: "Radiation Dose Measurement among Brain Spectral CT Pediatric Patients".

Submitted by: Hiba Nabeel Hamdi Qutop

Date received: 20th August 2024

Date reviewed: 26th August 2024

Date approved: 8th September 2024

Your Study titled "Radiation Dose Measurement among Brain Spectral CT Pediatric Patients" with the code number "R-2024/A/141/N" was reviewed by the Arab American University Institutional Review Board - Ramallah and it was approved on the 8th of September 2024.

Sajed Ghawadra, PhD
IRB-R Chairman
Arab American University of Palestine

Sajed



General Conditions:

1. Valid for 6 months from the date of approval.
2. It is important to inform the IRB-R with any modification of the approved study protocol.
3. The Board appreciates a copy of the research when accomplished.

رام الله - فلسطين

Tel: 02-294-1999

E-Mail: IRB-R@aaup.edu

Website: www.aaup.edu

Appendix 2: The indications of patients who have been examined using a CT scan for each group type

Indication	Group type	Total
Congenital disease	Infant	1
Craniosynostosis	Infant	1
Delayed development	Children	1
Epilepsy	2 Children 2 Adolescence	4
Falling	1 Neonates 13 Infants 18 Children 2 Adolescence	34
Fever	1 Infants 2 Children	3
Hand tremor	1 Adolescence	1
Head size	Infants	1
Headache	2 Infants 8 Children 4 Adolescence	14
Headache + dizziness	Children	1
Hydrocephalus	1 Infant 1 Children	2
Hydrocephalus bleeding	Neonates	1
Injury of lower back	Children	1
Leg cramps	Infants	1
Extremity weakness	1 Infants 1 Children	2
Malignant neoplasm of brain	1 Children 1 Adolescence	2
Malignant neoplasm with pain or falling	Infants	2
Newborn health examination	Infants	1
Pain	14 Infants 21 Children 7 Adolescence	42
Extremity weakness + Headache	1 Adolescence	1
Skull enlargement	Infant	1
Trauma	3 Infants 11 Children 8 Adolescence	22
Vomiting	Infants	1

ملخص الرسالة

مقدمة

تكنولوجيا التصوير المقطعي المحوسب، التي كانت في الأصل تركز على الصور الثابتة، قد تطورت لتشمل تحسينات مثل التصوير المقطعي الطيفي، الذي يحسن القدرات التشخيصية، خاصة الشبكات المعقدة في الدماغ، التي تشمل النظام عند تحليل المناطق التشريحية المعقدة مثل الدماغ البطيني والمادة الرمادية والبيضاء، هي ضرورية لوظائفه، مما يجعل فحوصات الأشعة المقطعية ضرورية للكشف عن الأمراض مثل إصابات الدماغ الرضحية والاورام الدماغية، خاصة في مرضى الأطفال.

الغرض

الهدف الرئيسي للدراسة هو تقييم التعرض للإشعاع من فحوصات التصوير المقطعي الطيفي والتصوير المقطعي متعدد الكواشف بين المرضى الأطفال الذين خضعوا لفحص التصوير المقطعي للدماغ . أنشاء نموذج مخصص لمرضى الأطفال للرأس لتقدير الجرعة الصحيحة للأطفال .

الطريقة

تبحث هذه الدراسة الاستيعابية في التعرض الإشعاعي المرتبط بفحوصات التصوير المقطعي المحوسب للدماغ للأطفال في جمعية أصدقاء الرحمة ومستشفى ريفيدا الجراحي، خلال الفترة من يناير إلى أكتوبر 2024. واستُخدمت التحليلات الإحصائية لتحديد الاختلافات في التعرض الإشعاعي بين أجهزة التصوير المقطعي المحوسب الطيفي وأجهزة التصوير المقطعي المحوسب متعدد الشرائح، مما يُبرز أهمية الممارسات الموحدة لتقليل مخاطر الإشعاع في تصوير الأطفال .

النتائج

تكشف النتائج أن أجهزة التصوير المقطعي المحوسب الطيفي تُصدر باستمرار جرعات إشعاعية أعلى مقارنةً بأجهزة التصوير المقطعي المحوسب متعدد الشرائح من فيليبس، وذلك عبر مقاييس مختلفة مثل حاصل طول الجرعة والجرعة الفعالة. كما يُظهر البحث أن طرق تقدير الجرعة القائمة على الموضع تُعطي أعلى وأدق تقديرات مقارنةً بالطرق الاسمية والتقنية القائمة على المحاكاة الوهمية .

الخلاصة

تبحث هذه الدراسة في تباين جرعات الإشعاع المرتبطة بفحوصات التصوير المقطعي المحوسب للرأس للأطفال، مسلطة الضوء على اختلافات جوهرية تتأثر بنوع الماسح الضوئي، وعمر المريض، وحجم الجسم، ومنهجيات تقدير الجرعة. تُصدر أجهزة التصوير المقطعي المحوسب عبر مقاييس جرعات متعددة. وتدعو الطيفي جرعات إشعاعية أعلى بكثير من أجهزة فيليبس الدراسة إلى وضع بروتوكولات متسقة خاصة بكل جهاز تصوير لفحوصات التصوير المقطعي

المحوسب للرأس للأطفال، وتدعو إلى استخدام معايير المسح الفعلية لضمان دقة تقييمات الجرعات .