

Radiation Dose Optimization Techniques in CT-Scan for Patient Safety in Radiology Departments in Tripoli, Libya.

■ Professor: Ali Masoud El-Mansuri *

● Received: 03/09/2025

● Accepted: 07/11/2025

■ Abstract:

In response to concerns about the increasing use of radiation exposure from the growing CT scan use and associated risks. This study aimed was to assess and sought to optimize radiation dose protocols in CT scans across radiology departments in Tripoli, Libya, to improve patient safety. The data from 140 patients who underwent brain, chest, abdomen-pelvis, and paranasal sinus (PNS) CT scans from two Central Hospital revealed statistically significant variations in doses for different procedures. The analysis included parameters such as tube current (MAS), tube voltage (KVP), computed tomography dose index (CTDI), and dose-length product (DLP). Statistical analyses, including ANOVA and Scheffe's test, revealed significant dose variations in radiation doses across different scan types and hospitals. Some effective radiation doses were analyzed using anatomical conversion factors, for instance, brain CT scans averaged 1.53 MSV while PNS scans averaged 2.62 MSV. This research study emphasized the importance of complying with the ALARA protocols and recommended protocol adjustments, such as adjusting tube current and optimizing scan length to minimize radiation exposure without compromising diagnostic quality.

- **Keywords:** Computed Tomography CT Scan, Radiation Dose Optimization, ALARA, Patient Safety, Dose Reduction Strategies.

* Technical College of Medical Sciences Email:ALI_mns62@yahoo.com

■ المستخلص:

أدى الانتشار المتزايد لاستخدام التصوير المقطعي المحوسب (CT) في الفحوصات التشخيصية إلى بروز مخاوف متزايدة بشأن مخاطر جرعات الإشعاع التي قد يتعرض لها المريض، و ما يمكن أن يترتب عليها من آثار صحية خطيرة. أن الهدف من هذه الدراسة البحثية هو لتقييم البروتوكولات المستخدمة في جرعات الاشعاع أثناء التصوير المقطعي خلال الفحوصات الطبية التي تجرى على المرضى في مدينة طرابلس، ليبيا، مع التركيز على أهمية تحسين هذه البروتوكولات من أجل رفع مستوى السلامة الاشعاعية للمرضى. أجريت هذه الدراسة على 140 مريضاً خضعوا لفحوصات مقطعية شملت الدماغ، و البطن و الصدر و الحوض و الجيوب الأنفية (PNS) في مستشفى طرابلس المركزي و مستشفى معيتيقة العسكري. و تم تحليل مجموعة من المعايير التقنية من بينها شدة التيار الكهربائي (MAS) و فرق الجهد (KVP) و مؤشر جرعة التصوير المقطعي (CTDI) ومنتج الطول الجرعة (DLP). استنادا إلى الاختبارات الإحصائية المستخدمة مثل اختبار ANOVA واختبار Scheffe ، فإن نتائج هذه الدراسة أظهرت وجود فروق ذات دلالة إحصائية في مستويات جرعات الإشعاع المختلفة سواء بين أنواع الفحوص أو بين هذين المستشفىين. كما تم قياس الجرعات الفعالة باستخدام معاملات التحويل التشريحية حيث بلغ متوسط الجرعة في فحص الدماغ 1.53 ملي سيفرت، بينما بلغ متوسط جرعة فحص الجيوب الأنفية 2.62 ملي سيفرت. و تؤكد نتائج هذه الدراسة أهمية الالتزام بمبدأ ALARA القائم على تقليل جرعات الاشعاع ادنى مستوى دوت الاثير على جودة التصوير المقطعي مع التوصية بتحديث البروتوكولات المعمول بها بما في ذلك خفض شدة التيار الكهربائي و تحسين و ضبط طول منطقة الفحص بهدف تقليل التعرض الاشعاعي و تعزيز فعالية التشخيص .

● الكلمات المفتاحية: التصوير المقطعي المحوسب (CT)، خفض جرعة الإشعاع، مبدأ ALARA، تحسين سلامة المرضى، استراتيجيات تقليل الجرعة، تحسين البروتوكولات.

1. Introduction

In recent years, concerns have grown regarding the health risks associated with low levels of ionizing radiation. Therefore, minimizing radiation exposure from diagnostic medical imaging is essential..(1) The first computed tomography (CT) scan was conducted in 1971 at Atkinson Morley Hospital in London using the original EMI-Scanner. This early system was limited to head scanning images, requiring nearly five minutes per slice and seven

minutes to reconstruct an 80×80 matrix image using two detectors along the z-axis. scan images were performed at tube voltages of 100 KVP (40 MA), 120 KVP (32 MA), or 140 KVP (27 MA), delivering an average skin dose of 11.66–14.67 MGY for three to four head. (2). Further to that, modern CT systems, in contrast, can acquire up to 320 slices in a single rotation taking less than 0.4 seconds, with reconstruction speeds of up to 18 images per second for a 512×512 matrix. Tube potential typically ranges from 80 to 140 KVP, with tube current reaching up to 800 MA. These advancements have significantly improved both image quality and patient comfort during scans. (3). However, the growing reliance on CT imaging, combined with its relatively high radiation doses per scan, contributes to significant cumulative exposure. Since the associated risk of radiation-induced cancer risk, which correlates with the radiation dose index from CT examinations, optimizing radiation dose is critically essential. (4)

There is no doubt that effective dose optimization can be achieved through several strategies, such as reducing the tube current, minimizing tube voltage-time product, and increasing pitch values. A solid understanding of CT scan parameters is vitally crucial for minimizing radiation exposure. (5)

Therefore, Computed Tomography (CT) remains an indispensable diagnostic tool, but its extensive use raises concerns about patient exposure to ionizing radiation, particularly, cancer. Balancing diagnostic accuracy with patient safety requires careful dose optimization. This study evaluates current CT protocols in used in radiology departments in Tripoli and examines strategies for dose reduction, including tube current modulation, KVP adjustment, and iterative reconstruction methods.

1.1 Aims of Research

The objectives of this study were:

- 1: To review the existing CT protocols with a special focus on radiation dose management.
- 2: To find out techniques or strategies for dose reduction such as tube current modulation, iterative reconstruction.
- 3: T examine how patient-related factors including age, sex, body size can

affect radiation exposure.

- 4: To compare various CT scanner models and scanning protocols to identify the most optimal settings.

1.2 Importance of Research

This study supports international global initiatives aimed to optimize CT radiation doses, prompting patient safety without compromising diagnostic accuracy. The findings offer evidence-based guidance for radiology departments in Libya and comparable health care environments.

2: Literature Review

Literature on CT radiation dose optimization emphasized the importance of maintaining diagnostic accuracy while ensuring patient safety. Mayo et al. (1995) carried out a study to identify the lowest tube current (MAS) that could provide adequate chest CT images. The subjects of the study included 30 patients (mean weight 68 kg; age >45 years) underwent scans at standard settings (120 kVp, 400 mAs) and at reduced tube currents (200, 140, 80, and 20 mAs). Two blinded observers rated image quality and assessed for mediastinal and lung abnormalities. The findings revealed that image quality at 200 and 140 mAs was comparable to the standard 400 mAs, while significant degradation occurred at 80 and 20 mAs. Importantly, the detection of abnormalities remained consistent across dose levels. The study concluded that reducing tube current from 400 to 140 mAs can significantly lower radiation exposure without affecting diagnostic reliability. (6)

In 2000, Cohnen et al. investigated the effects of lowering radiation dose by adjusting tube current and voltage on head CT images. A formalin-fixed cadaver was scanned on two CT systems in conventional and helical techniques, with surface doses measured and had five experts independently assessed image quality. The results showed that dose reductions up to 75% on one (scanner 1) and 60% on the other (scanner 2) were possible without observable loss of image quality. Even images with surface doses below 30 MGY were still remained diagnostically interpretable. The study concluded that while standard cranial CT parameters prioritize optimal image quality, radiation doses can be safely reduced by as much as 40% without

compromising diagnostic . (7)

Ravenel et al. (2001) explored the impact of tube current variations on radiation dose and image quality in unenhanced chest CT images. Around ten patients underwent CT-guided lung biopsies with six images acquired per patient at settings ranging from 40 to 280 MAS. Radiologists assessed the image quality based on noise levels. The result indicated that image quality remained stable above 160 MAS but declined significantly below this threshold. The authors concluded that tube current settings between 120 and 280 MAS provided a balance minimizing unnecessary radiation exposure and maintaining diagnostic image quality, while 40 Mas produced suboptimal images . (8)

McNitt-Gray (2002) presented an extensive review of radiation dose principles specific to CT, involving exposure, absorbed dose, effective dose, and CT-specific dose metrics as the CTDI (Computed Tomography Dose Index) and dose-length product (DLP). The review highlighted some key factors affecting dose include beam energy, tube current-time product, pitch, collimation, patient size, and dose reduction options. Additionally, it also outlined dose reduction methods such as lowering milliamperere-seconds, increasing pitch, and adjusting parameters on patient size and characteristics. The study also described approaches for dose estimation, including Monte Carlo simulations and the use of conversion factors.(9)

Livingstone et al. (2006) assessed strategies for optimizing radiation dose in brain CT exams using spiral CT techniques. In a cohort of 101 patients, effective doses were found to range between 0.65 and 0.93 Msv for full complete brain examinations and 0.28 to 0.53 MSV for partial scans. The findings showed that by adjusting dose reduction parameters, significant dose reduction could be achieved without compromising diagnostic accuracy. (10)

Prakash et al. (2010) conducted a study to compare radiation dose and image quality in weight adjusted chest CT examinations employing adaptive statistical iterative reconstruction (ASIR) versus the conventional filtered back projection (FBP) techniques. Among 152 patients, ASIR not only achieved significant dose reduction but also enhanced image quality consistently across all weight categories. (11)

Nakaura et al. (2011) conducted a study to examine how tube voltage and current-time product could influence abdominal CT imaging quality in thin adults. The finding of the study revealed that using 80 KVP with a higher tube current reduced effective radiation by as much as 33% compared to 120 KVP, while also enhancing the contrast-to-noise ratio without introducing additional artifacts. (12)

Thakur, McLaughlin, and Mayo (2013) examined how patient age and gender affect radiation sensitivity, emphasizing the importance of customizing CT scanning parameters to individual demographics. The study concluded that dose reduction technologies can significantly decrease radiation exposure while maintaining diagnostic image quality. (13)

Kalender (2014) reviewed CT scanner output metrics and patient dosimetry, highlighting substantial improvements in dose reduction technologies. The result concluded that it is possible to achieve effective doses below 1 MSV in certain applications. (14)

Al Mahrooqi, Ng, and Sun (2015) reviewed strategies for reducing radiation dose in pediatric CT dose-saving techniques. They identified techniques such as adjusting tube voltage and current, iterative reconstruction, and adjusting scan parameters according to patient age and body size. The study suggested optimized pediatric protocols specifically for 64-slice CT scanners to enhance safety while maintaining image quality.(15)

Kumar Sarangi (2017) stated that CT examinations could expose patients to higher levels of radiation doses 100 to 1,000 times higher than conventional X-rays, with an estimated 0.4% of cancers in the US linked to CT exposure. The study highlighted the importance of adherence to the ALARA principle and implementing special precautions for vulnerable populations including as children and pregnant women. (5)

Badawy, Lane, and Galea (2019) assessed the impact of targeted educational interventions on CT neck scan protocols. Following the intervention, the frequency of over scanning declined by 15%, scan length by 33%, and radiation dose dropped by 20%. The study showed that staff awareness and strict protocol adherence ca significantly minimize patient exposure. (16)

Yang (2020) carried out a study to examine dose metrics and their determinants in head, chest, and abdominal CT scans across six scanners, analyzing over 28,000 examinations to establish local diagnostic reference levels. Multi analyses showed some statistically significant correlations between CTDIvol and patient and scan parameters, maintaining the use of DRLs for dose optimization in line with ALARA principles. (17)

Whitebird, Solberg, and Chu (2022) used semi-structured interviews with leaders from healthcare systems in the US, Europe, and Japan to explore organizational strategies for CT dose optimization. They identified seven key approaches, including engaging radiologists and technologists, establishing CT dose committees, leadership support, continuous monitoring, protocol modification, and equipment updates. These approaches provided a framework for organizational initiatives to reduce patient radiation exposure. (18)

Finally, Alkhanova et al. (2023) investigated tube current modulation techniques for reducing radiation dose in CT while maintaining image quality. The study revealed that manufacturer-specific automatic current modulation programs influence image noise and patient dose in different ways. The study concluded that careful optimizing for scan examination protocols and parameters can achieve the lowest radiation dose required for accurate clinical problems effectively. (19)

3. Materials and Methods

3.1 Study Design and Data Collection

Sample: this prospective study consisted of 140 patients undergoing CT scans of the brain, chest, abdomen-pelvis, PNS at Mitiga Military Hospital (Philips CT 128-slice) and Tripoli Central Hospital (Toshiba CT 64-slice).

The study was conducted in Spring , 2025. Patients undergoing diagnostic CT scans (brain, Para nasal sinuses, chest, abdomen, pelvis) patients scheduled for diagnostic CT scan in the specific regions were included.

Protocols: all scans were performed at 120 KVP fixed tube voltage, with variable tube current MAS (200–500), slice thickness 2–3 mm, using sequential scanning mode.

Data collection: information about patient demographics, scan parameters (tube current MAS, slice thickness, rotation time, pitch, total scan time), and dose descriptors (CTDIvol, DLP) were recorded.

Procedure: scans were carried out using manufacturer-recommended protocols, with some adjustments made by radiology staff to improve image quality and reduce radiation exposure.

Analysis: Data were analyzed by using SPSS and findings were categorized according to body region.

4. Findings

4.1. Gender Distribution

Table 1. Gender Distribution by Scan Type

Scan Type	Male (%)	Female (%)
Abdomen-Pelvis	53%	47%
Paranasal Sinus (PNS)	36%	64%
Chest	76%	24%
Brain	70%	30%

Table 1 shows the distribution of scans about genders revealing clear variations by anatomical region. Abdomen–pelvis scan examinations were relatively balanced, with males representing around 53% and females accounting for 47%, indicating minimal gender disparity. In contrast, paranasal sinus (PNS) scans were more predominantly carried out in females (64%), indicating a higher clinical burden for sinus-related conditions in this group. Chest scans showed a marked male predominance (76% versus 24%), which may potentially reflect the greater incidence of respiratory or thoracic pathologies among male patients. Similarly, brain scans were more greatly conducted in male patients accounting for (70% compared to 30% female), pointing to possible gender differences in neurological disease occurrence or referral practices.

Radiation Dose Optimization Techniques in CT-Scan for Patient Safety in Radiology Departments in Tripoli, Libya.

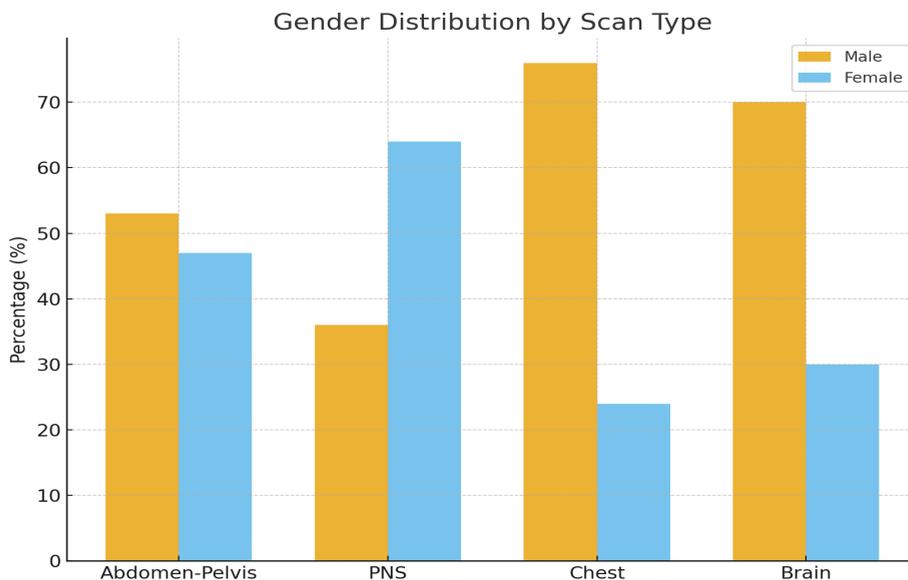


Figure 1

Table 2. CT Scan Protocols Used

Parameter	Value	Range	Notes
Tube Voltage (KVP)	120	Fixed	Manufacturer recommended
Tube Current (MAS)	200–500	Variable	Adjusted by staff
Slice Thickness (mm)	2–3	-	Sequential mode
Rotation Time	0.5–1s	-	As per machine protocol
Pitch	Standard	-	Machine dependent

Table 2 presents the analysis of variance (ANOVA) , which identified statistically significant differences across anatomical regions for several parameters. Tube current (mAs) differed considerably between scan types ($F = 6.01, p = 0.001$), reflecting protocol adjustments aligned with different anatomical requirements. Likewise, both CTDI ($F = 57.30, p = 0.001$) and

DLP ($F = 8.25, p = 0.001$) exhibited substantial variations, indicating region-specific differences in radiation dose exposure. Additionally, patient age revealed significant variability across scan types ($F = 6.27, *p* = 0.001$), indicating that demographic characteristics influenced the distribution of scans which may potentially play a role in the optimization of dose parameters. Overall, these findings stress that radiation dose and scanning parameters are not uniform but shaped by the anatomical region examined in conjunction with patient-related factors.

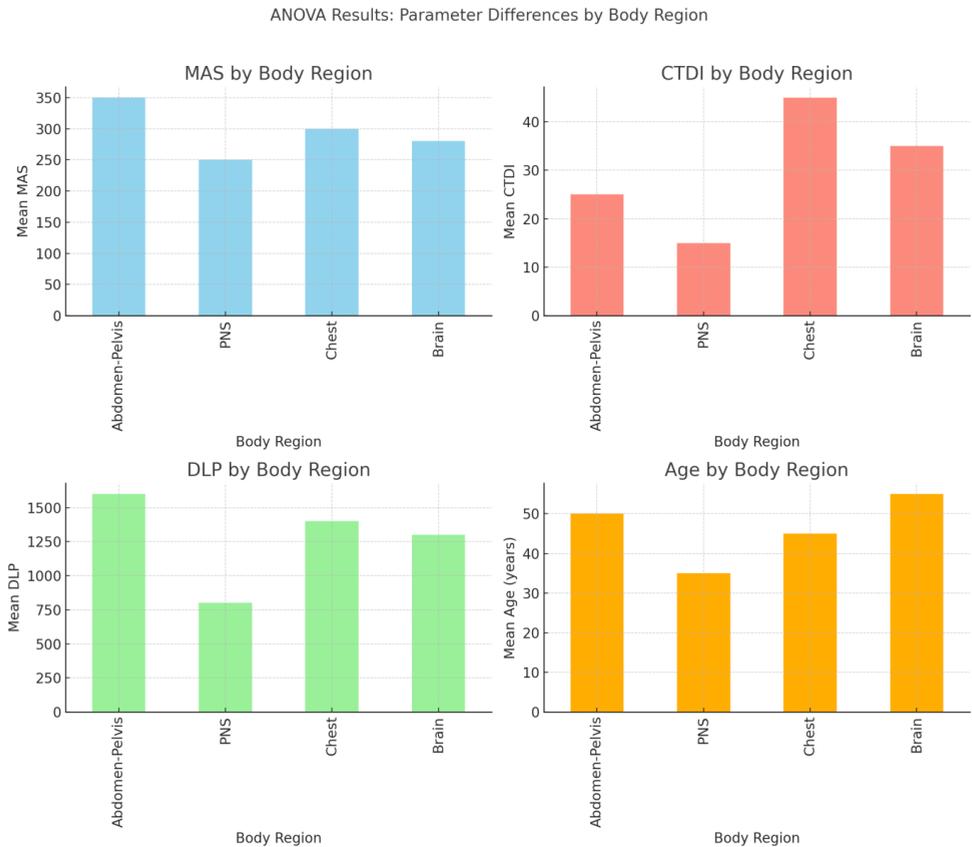


Figure 2

Radiation Dose Optimization Techniques in CT-Scan for Patient Safety in Radiology Departments in Tripoli, Libya.

Table 3. Comparison of Parameters between Hospitals

Parameter	Mitiga (Mean)	Tripoli (Mean)	p-value	Significance
MAS	301.7	235.9	0.084	Not significant
CTDI	20.1	54.9	<0.001	Significant
DLP	1549.9	1239.5	0.312	Not significant
Age (years)	48.6	40.0	0.057	Near significant

Table 3 summarizes the comparative analysis between Mitiga and Tripoli hospitals, indicating variations in scanning practices and patient demographics. The mean tube current (mAs) was higher at Mitiga hospital with (301.7) than in Tripoli hospital with (235.9), although, this variation did not lead to a statistical significance ($p = 0.084$). By comparison, CTDI values were significantly greater at Tripoli hospital representing (54.9) than at Mitiga hospital with (20.1), ($p < 0.001$), marking a substantial difference in dose delivery protocols. The dose-length product (DLP) was marginally higher at Mitiga hospital with (1549.9) than at Tripoli (1239.5), although this variation was not statistically significant ($p = 0.312$). Patient demographic differences were also observed, with patients at Mitiga hospital being older on average (48.6 years) compared to those at Tripoli (40.0 years), a difference that reached statistical significance at ($p = 0.057$). collectively, these results suggest that the inter-hospital differences could be attributed to patient population characteristics and to institutional practices regarding protocol selection and dose optimization strategies.

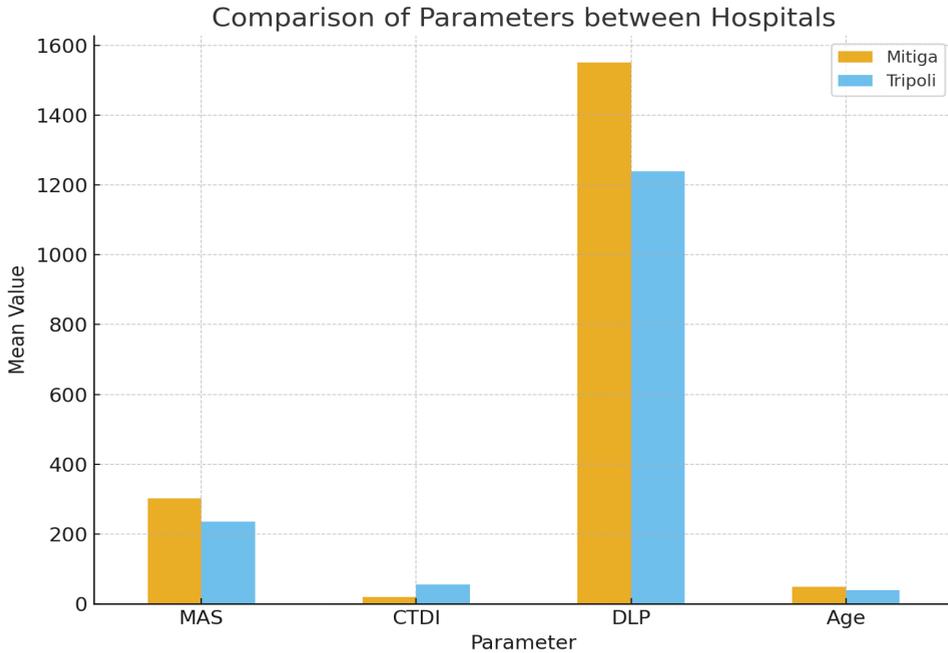


Figure 3

5. Discussion

The results of this research study revealed significant variations in radiation dose parameters and patient demographics across different CT examinations and between institutions. These findings align with and add to existing literature the evidence from previous studies.

5.1. Gender Distribution:

The gender related differences observed in this study, namely, the predominance of males undergoing more chest and brain CT scans and the higher proportion of females in PNS examinations while females predominated in PNS scans, which indicate possible variations in disease prevalence or clinical referral patterns. Although previous research has not extensively examined gender-based use of CT scan imaging, Thakur, McLaughlin, and Mayo (2013) stressed the impact of gender and age on radiation sensitivity, emphasizing the significance of adjusting scan protocols to demographic characteristics. This finding reinforces the need to consider not only anatomical but also demographic factors when optimizing CT protocol.

5.2. Dose and Scan Parameter Variations:

The significant differences in MAS, CTDI, DLP, and patient age across anatomical regions showed that scanning parameters are closely shaped by body part examined and the corresponding clinical need. McNitt-Gray (2002) pointed out that radiation dose is highly dependent on technical factors such as tube current, voltage, pitch, and patient size. Likewise, Livingstone et al. (2006) demonstrated reported variations in brain versus partial CT exams indicating the influence of anatomical site on exposure levels. These findings therefore align with the research evidence that anatomical site is a key factor of radiation exposure which requires targeted dose optimization to ensure both diagnostic accuracy and patient safety.

5.3. Institutional Comparison (Mitiga vs. Tripoli):

The marked discrepancy in CTDI between Tripoli hospital (higher) and Mitiga hospital (lower), in spite of the comparable MAS and DLP values, pointing to significant differences in scanning protocols, equipment calibration, or operator practices. This finding is in consistent with the finding of Yang (2020) who reported strong correlations between CTDI_{vol} and institutional practices, and Badawy, Lane, and Galea (2019) demonstrated that staff training and standard protocol adherence significantly reduce radiation dose levels. Therefore, the results of this study are in agreement with the literature in demonstrating that institutional policies and equipment factors can significantly play a critical role in radiation exposure, suggesting the need to implement standardized local diagnostic reference levels (DRLs) to harmonize practices, optimize patient safety, and maintain consistent imaging quality.

5.4. Body Part Differences:

Brain CT scan images in this research study were linked to the highest CTDI, whereas abdomen-Pelvis scans revealed the highest DLP values which are attributed to longer scan lengths. This finding matches the findings of Cohnen et al. (2000), who found that anatomical site strongly influences achievable dose reductions without compromising image quality. Similarly, the finding of Nakaura et al. (2011) indicate that abdominal CT protocols

require careful adjustment of voltage and current to achieve a great balance between radiation dose with diagnostic accuracy. Together, these findings emphasize the importance of a site-specific approach to dose optimization stressing that technical parameters and anatomical considerations must be carefully balanced to maintain patient safety while ensuring diagnostic accuracy.

5.5. Effective Dose Calculations:

The effective dose estimated level derived in this study were 1.53 MSV for brain CT, 2.62 MSV for PNS CT, and 4.64 MSV for abdomen-pelvis CT which fall within internationally reported ranges. This finding is therefore, consistent with the finding of Livingstone et al. (2006) and Kalender (2014), who found that brain CT effective doses ranging from below 1 MSV up to approximately 2 MSV, and abdomen-pelvis doses were estimated at 5 MSV. This alignment validates the accuracy and reliability of our dose assessment techniques and further reinforces the global consensus that although current doses generally remain within acceptable ranges, ongoing optimization remains critically essential to ensure adherence to the ALARA (As Low As Reasonably Achievable) principle.

Overall, together, these findings corroborate and extend the current literature emphasizing that radiation dose optimization in CT scan imaging should consider patient demographics, anatomical site, and institutional protocols. The findings of this study further highlight the practical importance of implementing scanning standardized protocols, providing continuous training, and establishing local diagnostic reference levels DRLs to improve patient safety while ensuring diagnostic quality.

Limitations of the Study

This study has a number of limitations that should be acknowledged. First, the small sample size for paranasal sinus (PNS) scans, which may statistically limit the analyses in this subgroup. Second, the data derived on pediatric patients were limited, which may restrict the applicability of the findings to younger generations. Finally, although the study was carried out in only two hospitals, the findings may not be generalizable to other hospitals or regions with different scanning standards, equipment, or patient characteristics.

6. Conclusion

In Libya, the increasing use of computed tomography (CT) scanning has led to greater radiation exposure for patients. This rise could be attributed to the expanding availability of CT units across general hospitals, medical centers, and private clinics. Until recently, there is a greater demand from medical specialists and clinicians who rely extensively on CT scanning systems for clinical diagnosis and therapeutic treatment decisions. Despite, the availability of rapid progress and information provided by CT scanning, medical specialists and clinicians should not replace a clinical evaluation for all patients undergoing radiation scanning imaging assessments. Although CT scan imaging provides valuable diagnostic information, referring clinicians must maintain their awareness of the associated radiation risks and the need for judicious use. Whenever feasible, alternative imaging systems that do not include ionizing radiation should be considered to address any possible following clinical questions. There is a widespread consensus that current levels of CT radiation exposure have potentially resulted in the increased risks of cancer and other radiation-related health problems. Therefore, referring physicians and clinicians should assess the need for each CT scan and use non-invasive imaging techniques where possible. Careful attention must be given to protecting patients radiosensitive organs such as breasts, eye lenses, thyroid, and gonads, particularly in pediatric and young patients, as these organs are often directly exposed to the x-ray beam. CT technologists should implement appropriate protective measures accordingly. Radiologists and imaging specialists must continuously balance patient radiation dose against the need for image quality in every diagnostic study. Finally, adherence to the ALARA principles of keeping doses “As Low As Reasonably Achievable” (ALARA) is critically essential to optimize patient safety without compromising diagnostic accuracy.

■ Recommendations for optimization

Based on the results of this study, the following organizational and technical strategies and recommendations are made to optimize CT radiation doses:

1. The engagement of radiologists, technologists, and other stakeholders in establishing a CT dose committee to monitor dose optimization

initiatives and implement improvement strategies.

2. The continuous review and modification of CT scan protocols to minimize unnecessary radiation exposure and to identify areas for optimization and ensure adherence to international protocols.
3. Upgrade and maintain CT equipment to ensure dose-efficient performance by regularly evaluating and updating CT scan protocols to reduce unnecessary radiation exposure.
4. Restrict the scanning range to the minimal need for the clinical indication to operate in a dose-efficient manner to reduce dose.
5. Optimization of multi-detector CT parameters to adjust dose, by adjusting detector configuration, tube current (MAS), kilovoltage peak (KVP), reconstruction algorithms, patient positioning, scan range, slice thickness, and pitch to achieve optimal dose efficiency.
6. The use of automated dose modulation by employing tube current modulation systems with careful consideration, especially in patients who are obese, pediatric patients, or those patients with metallic implants, as these conditions may affect dose modulation effectiveness.
7. Accurate patient positioning by ensuring precise patient alignment within the scanner to prevent unnecessary increase in radiation dose.
8. Continuous training and education by offering CT technologists and radiologists ongoing professional development to reinforce best practices in dose optimization and raise awareness of radiation safety practices and awareness.
9. Implementation of these strategies and recommendations is expected to improve patient safety, minimize unnecessary radiation exposure, and improve the quality of CT imaging systems and services in Libya.

■ **References**

- (1) Meredith, W. J. (2008). Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. *International Journal of Radiation Biology*, 12(1), 100.
- (2) Ben Rabaa, A. A., Tikala, S. M., Elmansuri, A. M., Hilan, B. M., & Ben, M. M. (2020, November). *Determination of radiation dose for the brain during CT scanning*. 28–30.
- (3) World Health Organization. (2013). *Radiation dose in X-ray and CT exams* (pp. 1–6).
- (4) McCollough, C. H., Primak, A. N., Braun, N., Kofler, J., Yu, L., & Christner, J. (2009). Strategies for reducing radiation dose in CT. *Radiologic Clinics of North America*, 47(1), 27–40.
- (5) Sarangi, P. K. (2017). Understanding computed tomography (CT) dose reduction techniques and principles in a simplified way. *Current Trends in Clinical & Medical Imaging*, 1(2).
- (6) Mayo, J. R., Hartman, T. E., Lee, K. S., Primack, S. L., Vedal, S., & Muller, N. L. (1995). CT of the chest: Minimal tube current required for good image quality with the least radiation dose. *American Journal of Roentgenology*, 164(3), 603–607.
- (7) Cohnen, M., Fischer, H., Hamacher, J., Lins, E., Kotter, R., & Modder, U. (2000). CT of the head by use of reduced current and kilovoltage: Relationship between image quality and dose reduction. *American Journal of Neuroradiology*, 21(9), 1654–1660.
- (8) Ravenel, J. G., Scalzetti, E. M., Huda, W., & Garrisi, W. (2001). Radiation exposure and image quality in chest CT examinations. *American Journal of Roentgenology*, 177(2), 279–284.
- (9) McNitt-Gray, M. F. (2002). AAPM/RSNA physics tutorial for residents: Topics in CT—Radiation dose in CT. *RadioGraphics*, 22(6), 1541–1553.
- (10) Livingstone, R. S., Eapen, A., Dip, N. B., & Hubert, N. (2006). Achieving reduced radiation doses for CT examination of the brain using optimal exposure parameters. *Indian Journal of Radiology and Imaging*, 16(2), 247–251.
- (11) Prakash, P., et al. (2010). Radiation dose reduction with chest computed tomography using adaptive statistical iterative reconstruction technique: Initial experience. *Journal of Computer Assisted Tomography*, 34(1), 40–45.
- (12) Nakaura, T., et al. (2011). Low-kilovoltage, high-tube-current MDCT of liver in thin adults: Pilot study evaluating radiation dose, image quality, and

- display settings. *American Journal of Roentgenology*, 196(6), 1332–1338.
- (13) Thakur, Y., McLaughlin, P. D., & Mayo, J. R. (2013). Strategies for radiation dose optimization. *Current Radiology Reports*, 1(1), 1–10.
- (14) Kalender, W. A. (2014). Dose in X-ray computed tomography. *Physics in Medicine & Biology*, 59(3), R129–R150.
- (15) Al Mahrooqi, K. M. S., Ng, C. K. C., & Sun, Z. (2015). Pediatric computed tomography dose optimization strategies: A literature review. *Journal of Medical Imaging and Radiation Sciences*, 46(2), 241–249.
- (16) Badawy, M. K., Lane, H., & Galea, M. (2019). Radiation dose associated with overscanning in neck CT. *Current Problems in Diagnostic Radiology*, 48(4), 359–362.
- (17) Yang, C. C. (2020). Evaluation of impact of factors affecting CT radiation dose for optimizing patient dose levels. *Diagnostics*, 10(10), 787.
- (18) Whitebird, R. R., Solberg, L. I., & Chu, P. (2022). [Article]. *Journal of Patient Safety*, Advance online publication.
- (19) Alkhanova, A., Zhumadilov, K., Dautov, T., & Abdykalyk, G. (2023). Methods of optimizing the radiation dose during computed tomography. *Bulletin of L.N. Gumilyov Eurasian National University, Physics & Astronomy Series*, 142(1), 26–32.