Performance of Iterative Reconstruction in Image Space Algorithm in Combination with Automatic Tube Current Modulation Compared to Filtered Back Projection in Brain CT Scan

Salman Jafari (PhD)[1]*, Sohrab Kolivand (MD)[2]

[1]Department of Radiology Technology, School of Paramedicine, Hamadan University of Medical Sciences, Hamadan, Iran
[2]Department of Radiology, School of Medicine, Hamadan University of Medical Sciences, Hamadan, Iran

ABSTRACT

Background: High-quality images with minimum radiation dose are considered a challenge in Computed Tomography (CT) scans.

Objective: The current study aimed to assess the efficacy of the Iterative Reconstruction in Image Space (IRIS) algorithm combined with Automatic Tube Current Modulation (ATCM) compared to Filtered Back Projection (FBP) in brain CT scans.

Material and Methods: In this cross-sectional study, 200 patients underwent to brain CT scan, and images were then reconstructed using both FBP and IRIS. The CT Number (CTN), noise, and Signal-to-Noise Ratio (SNR) were computed for different tissues from CT images. The performance of two algorithms under different exposure conditions was evaluated using a water phantom. Two experienced radiologists assessed the image quality. Volume CT Dose Index ($CTDI_{vol}$) and Dose Length Product (DLP) were recorded for each scan.

Results: FBP reconstruction exhibited higher noise and lower SNR compared to IRIS, both with and without ATCM. Noise levels significantly increased for FBP combined with ATCM. Subjective analysis showed higher performance for IRIS without ATCM compared to other approaches. The mean $CTDI_{vol}$ with and without ATCM was 20.04±3.33 and 36.37±4.65 mGy, respectively. In the phantom study, the noise with IRIS remained lower than that with FBP even with a 42% dose reduction.

Conclusion: IRIS algorithm can preserve the image quality when radiation dose is significantly reduced by ATCM in brain CT scan. Implementation of IRIS combined with ATCM is recommended for brain CT examinations.

Citation: Jafari S, Kolivand S. Performance of Iterative Reconstruction in Image Space Algorithm in Combination with Automatic Tube Current Modulation Compared to Filtered Back Projection in Brain CT Scan. *J Biomed Phys Eng*. 2024;14(4):379-388. do: 10.31661/jbpe.v0i0.2404-1741.

Keywords

Brain; Tomography, X-Ray Computed; Radiation Dosages; Image Reconstruction; Image Quality Enhancement

Introduction

Computed Tomography (CT) scans, the gold standard [1-3], are the most requested examination for the brain [4]. However, CT scans expose patients to ionizing radiation, which can have potential health risks at higher doses [5-7]. The radiation was absorbed by various brain structures during CT scans [8]. For example, the cranium received 2.57–3.47 cGy, and the brain absorbed 2.34–3.78 cGy. Notably, the lens of the eye received a higher dose (2.51–5.03 cGy),

*Corresponding author:
Salman Jafari
Department of Radiology Technology, School of Paramedicine, Hamadan University of Medical Sciences, Hamadan, Iran
E-mail:
sa.jafari@umsha.ac.ir

Received: 1 April 2024
Accepted: 22 June 2024

highlighting the importance of proper shielding during the procedure [9] considering these findings, implementing strategies to minimize radiation dose is crucial in brain CT scans.

In this regard, some solutions are considered, including Diagnostic Reference Levels (DRLs), Automatic Tube Current Modulation (ATCM), dynamic shielding, and iterative reconstruction algorithms [10-12]. The most of the dose reduction strategies result in deteriorated image quality due to an increase in noise level [13]. Hence, dose reduction methods that preserve the image quality are of high importance.

For CT scans, the reconstruction algorithm significantly affects image clarity; Filtered Back Projection (FBP), as the most common method, is implemented in CT scanners [14], with some significant challenges for decreasing the dose and the increasing noise level, both leading to reducing the image quality [15].

Iterative Reconstruction in Image Space (IRIS) is an algorithm specifically designed to maintain image quality during dose reduction [16] with superior performance compared to FBP. In a phantom study, IRIS successfully decreased noise levels while preserving spatial resolution, CT number accuracy, and linearity [17]. Additionally, image noise and 29% higher Contrast-to-Noise Ratio (CNR) are substantially reduced for IRIS compared to FBP under equivalent tube voltage and tube current [18].

Despite its efficacy, most CT technicians do not use the IRIS because of insufficient training in this area. ATCM, also referred to as CARE dose 4D on Siemens scanners, is an effective solution for dose reduction in CT scans, which works well when the reference milliamperes (mA) setting is correct, and an accurate topogram is taken from the patients [19]. Selecting the optimal reference mA is crucial since its low value can lead to excessive image noise, compromising image quality. Conversely, an excessively high reference mA can negate the intended dose reduction benefits.

The use of ATCM when IRIS is used for reconstruction sounds like a good idea for dose reduction in CT scans without compromising image quality. To the best of our knowledge, no prior study has examined the impact of IRIS in conjunction with ATCM on both radiation dose and image quality in brain CT scans. Therefore, this study aimed to assess the efficacy of IRIS compared to FBP in brain CT examinations.

Material and Methods

Patient population

This cross-sectional study was conducted from September 2022 to March 2024. A total of 200 patients underwent to brain CT scan and informed consent before the study. The study protocol was approved by the research ethics committee of Hamadan University of Medical Sciences. Only images with normal reports were selected for analysis to decrease the influence of pathologies or other conditions on CT number and noise of brain tissue. Table 1 presents the number (N), average age, and sex of patients stratified by ATCM. Patient ages ranged from 12 to 85 years, and no significant difference was observed between the two groups (*P*-value>0.05).

Imaging protocol

This study employed a Siemens SOMATOM Scope, a 16-slice CT scanner, for brain CT scans. Following a preliminary lateral topogram, all patients underwent sequential scans encompassing the area from the foramen magnum to the vertex (Table 2). Both FBP and IRIS reconstruction algorithms were applied to all images. To assess the performance of FBP and IRIS under varying radiation exposure conditions, a water phantom was scanned using a range of acquisition parameters. Each scan was repeated three times for consistency. Due to its uniform composition and cylindrical shape, the water phantom was scanned

Table 1: The average age of patients stratified by sex and automatic tube current modulation (ATCM).

Gender	With ATCM		Without ATCM		P-value
	N	Age(year) Mean±SD	N	Age(year) Mean±SD	
Men	53	49.71±16.71	49	41.63±24.82	*P*>0.05
Women	47	38.71±26.63	51	39.11±29.31	

ATCM: Automatic Tube Current Modulation, SD: Standard Deviation

Table 2: Acquisition parameters for CT scan of the brain and water phantom.

Scan	kVp	mAs (Mean±SD)	Rotation time(s)	Slice thickness (mm)	Collimation (mm)	Kernel	Window level (HU)	Window level (HU)
Patient Without ATCM	110	251.73±38.15	1	4.8	16×1.2	FBP(H31s) IRIS(J30s)	120	40
Patient with ATCM	110	130.91±26.55	1	4.8	16×1.2	FBP(H31s) IRIS(J30s)	120	40
Phantom	130	136	1	5	2×5	FBP(H31s) IRIS(J30s)	100	40
Phantom	110	152	1	5	2×5	FBP(H31s) IRIS(J30s)	100	40
Phantom	110	114	1	5	2×5	FBP(H31s) IRIS(J30s)	100	40
Phantom	80	220	1	5	2×5	FBP(H31s) IRIS(J30s)	100	40
Phantom	80	130	1	5	2×5	FBP(H31s) IRIS(J30s)	100	40

ATCM: Automatic Tube Current Modulation, SD: Standard Deviation, FBP: Filtered Back Projection, IRIS: Iterative Reconstruction in Image Space, HU: Hounsfield Unit

only with ATCM. Noise and SNR were determined by measuring designated ROIs within the CT images.

Image quality

Image quality was objectively evaluated by quantifying the CT Number (CTN), noise, and SNR for gray matter, white matter, Cerebrospinal Fluid (CSF), and water. This was accomplished by delineating an ROI with an area ranging from 60 to 90 mm² on each tissue.

Figure 1 shows axial images at the level of lateral ventricles and location of the ROIs. The standard deviation (SD) within the ROI was measured as noise, while the SNR was calculated, as follows [20]:

$$SNR = \frac{CTN_{tissue}}{SD_{tissue}} \tag{1}$$

where CTN denotes the CT number of tissue, and SD represents the standard deviation.

Two blinded experienced radiologists assessed image quality based on noise, artifacts, edge sharpness, and contrast using a five-point Likert scale: (1) poor and non-evaluable image quality, (2) fair but compromised image quality, (3) good but minimally compromised

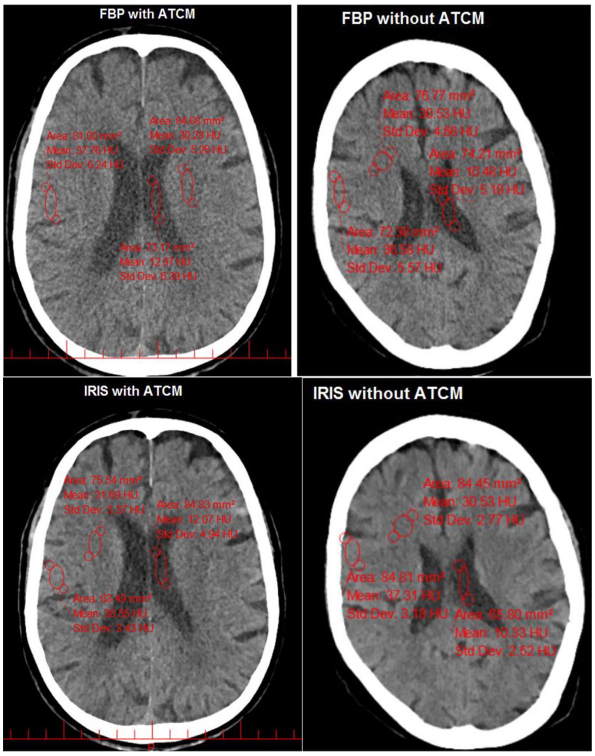

Figure 1: Objective evaluation of image quality by drawing of region of interest (ROI) on gray matter, white matter, and cerebrospinal fluid (CSF) at the level of lateral ventricular. (FBP: filtered back projection, ATCM: Automatic Tube Current Modulation, IRIS: Iterative Reconstruction in Image Space, HU: Hounsfield Unit)

image quality, (4) very good image quality, and (5) very high image quality.

Radiation dose evaluation

The Volume Computed Tomography Dose Index ($CTDI_{vol}$) and DLP are routinely displayed by the scanner software for each scan. These metrics can be used for radiation dose monitoring. The $CTDI_{vol}$ and DLP were recorded for each patient.

Figure of merit

The Figure of Merit (FOM) is a comprehensive metric for evaluating both radiation dose and image quality in CT scans. To assess these factors, the FOM was calculated, as follows [21]:

$$FOM = \frac{SNR^2}{CTDI_{vol}}(2) \tag{2}$$

Statistical analysis

Data analysis was performed using SPSS software version 22. The Kolmogorov-Smirnov test was used to assess the normality of data distribution. The Mann-Whitney U test was employed to compare the means of noise, SNR, FOM, and $CTDI_{vol}$, with statistical significance set at P-value<0.05. Inter-observer agreement between the two radiologists was evaluated using the kappa coefficient.

Results

Image quality objective analysis

Table 3 summarizes the mean and SD of CT numbers for gray matter, white matter, and CSF, categorized by reconstruction algorithm (FBP and IRIS) and automatic tube current modulation (ATCM) use. The Mann–Whitney test did not reveal significant differences in CT number for gray matter, white matter, CSF, and water between the FBP and IRIS algorithms, both with and without ATCM (P-value>0.05). Notably, the CT number of gray matter was higher than that of white matter and CSF for both FBP and IRIS algorithms.

Figure 2 shows the effect of ATCM on the noise and SNR of gray matter, white matter, and CSF for the IRIS algorithm compared to FBP. All tissues exhibited higher noise levels for FBP compared to IRIS (P-value<0.05) both with and without ATCM. Additionally, the differences in SNRs for gray matter, white matter, and CSF between IRIS and FBP were statistically significant (P-value<0.05). FBP reconstructions with ATCM exhibited a statistically significant increase (P-value<0.05) in noise levels across all tissue types. Conversely, the increase in noise level for IRIS was not significant (P-value>0.05). However, the combination of ATCM with FBP led to a

Table 3: The mean and standard deviation of CT numbers of gray matter, white matter, and cerebrospinal fluid (CSF) for iterative reconstruction in image space (IRIS) algorithm compared to filtered back projection (FBP).

ATCM	Tissue	Algorithm	CT number (Mean±SD)	*P*-value
With	gray matter	FBP	36.74±2.75	>0.05
		IRIS	37.08±2.62	
	white matter	FBP	31.3±2.67	>0.05
		IRIS	31.49±2.49	
	CSF	FBP	11.5±2.15	>0.05
		IRIS	11.37±2.11	
Without	gray matter	FBP	38.23±2.01	>0.05
		IRIS	38.78±2.18	
	white matter	FBP	31.26±6.24	>0.05
		IRIS	32.7±2.76	
	CSF	FBP	11.02±2.2	>0.05
		IRIS	11.31±1.73	

ATCM: Automatic Tube Current Modulation, SD: Standard Deviation, FBP: Filtered Back Projection, IRIS: Iterative Reconstruction in Image Space, CSF: Cerebrospinal Fluid

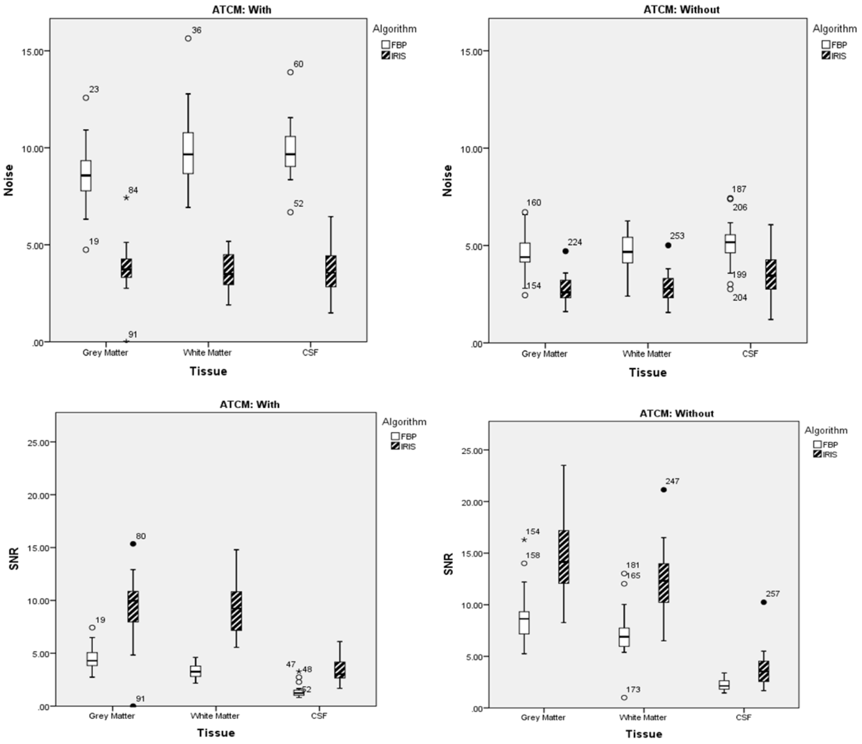

Figure 2: The effect of automatic tube current modulation (ATCM) on noise and signal to noise ratio (SNR) of gray matter, white matter, and cerebrospinal fluid (CSF) for iterative reconstruction in image space (IRIS) algorithm compared to filtered back projection (FBP).

significant reduction in SNR for all tissues under study (*P*-value<0.05), IRIS prevented a significant reduction in SNRs for applied ATCM (*P*-value>0.05).

In the phantom study, the SNR of water was higher for IRIS compared to that for FBP at all dose levels. The radiation doses in terms of $CTDI_{vol}$ were as follows: 26.17, 20.03, 15.03, 12.98, and 7.67 mGy, and the corresponding SNRs were 0.18, 0.16, 0.14, 0.09, and 0.08 for FBP, and 0.27, 0.22, 0.20, 0.16, and 0.10 for IRIS, respectively. The SNR of water with IRIS was higher than that with FBP (0.20 vs. 0.18), but the noise was lower (3.46 vs. 3.84) for dose reduction by 42% (from 26.17 to 15.03 mGy), showing IRIS can preserve image quality in dose radiation reduction. Additionally, under equal conditions, the noise of water was lower for IRIS compared to that for FBP at all dose levels.

Image quality subjective analysis

Table 4 illustrates the mean and SD of the image scores, categorized by the reconstruction algorithm and ATCM. The calculated Kappa coefficient exceeded 0.80, showing strong agreement between radiologists (*P*-value<0.001 for all images). Among all approaches, IRIS without ATCM received the highest score, followed by IRIS with ATCM, FBP without ATCM, and FBP with ATCM, respectively.

Radiation Dose

Figure 3 illustrates the $CTDI_{vol}$ and DLP values categorized by ATCM, presenting $CTDI_{vol}$ 20.04±3.33 mGy and 36.37±4.65 mGy with and without ATCM, respectively (*P*-value<0.05). Similarly, DLP values were 237.76±51.06 mGy.cm with ATCM and 532.4±94.67 mGy.cm without ATCM

Table 4: The mean and standard deviation of image score in terms of reconstruction algorithm and Automatic tube current modulation (ATCM).

Algorithm and ATCM	Score(0-5) (Mean±SD)	Kappa coefficient	*P*-value
FBP+ATCM	3.81±0.58	0.82	<0.01
IRIS+ATCM	4.06±0.79	0.91	<0.01
FBP-ATCM	3.99±0.98	0.86	<0.01
IRIS-ATCM	4.45±0.43	0.87	<0.01

ATCM: Automatic Tube Current Modulation, SD: Standard Deviation, FBP: Filtered Back Projection, IRIS: Iterative Reconstruction in Image Space

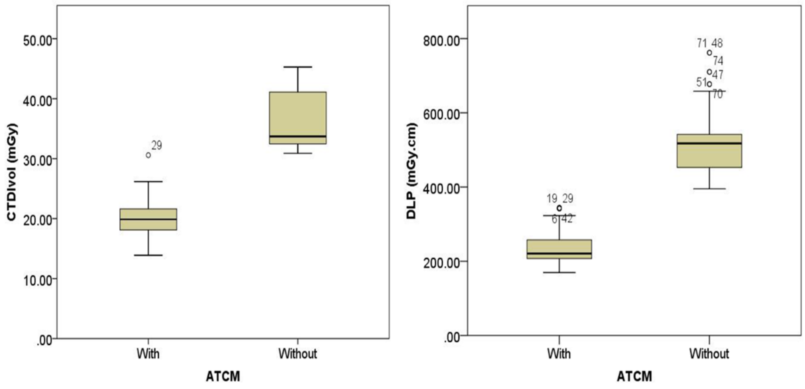

Figure 3: Volume CT dose index ($CTDI_{vol}$) and dose length product (DLP) in terms of automatic tube current modulation (ATCM) in brain CT scan.

(P-value<0.05). The radiation dose was significantly reduced with applied ATCM.

Figure of merit

Figure 4 depicts the FOM for IRIS and FBP algorithms categorized by ATCM. Although the FOM for IRIS without ATCM was higher than that for IRIS with ATCM, the difference was not statistically significant (P-value=0.62). Similarly, FBP without ATCM showed a higher FOM compared to FBP with ATCM, but the difference was also not statistically significant (P-value=0.11). The FOM for IRIS was significantly higher than that for FBP in both with and without ATCM conditions (P-value<0.05).

Discussion

Based on the results, IRIS reconstruction, compared to FBP, does not change the CT numbers of gray matter, white matter, and CSF, which is a significant finding due to the importance of CT numbers for accurate tissue identification in CT scans. However, there's a slight difference in CT numbers between gray and white matter, any deviation can potentially compromise diagnosis. Therefore, IRIS is particularly beneficial in situations demanding precise tissue differentiation, such as identifying brain strokes.

With the same radiation dose, IRIS significantly reduced image noise compared to FBP, due to IRIS's regularization procedure [22]. The low level of noise is crucial for accurate detection of acute ischemia, edema, or hemorrhage in brain CT scan. Furthermore, IRIS yielded higher SNR, FOM, and subjective scores compared to FBP. Since SNR is the ratio of the CT number over noise, a decrease in noise results in an increase in SNR. Compared to FBP, studies have shown that IRIS reconstruction in brain CT scans leads to: 1) reduced image noise, 2) enhanced subjective image quality, and 3) perceiving the images as sharper and more detailed.

Furthermore, IRIS can fully compensate for the reduction in image quality by lowering radiation dose by 15%, leading to safer CT scans while maintaining diagnostic accuracy [23]. In the present study, IRIS preserved image quality even at a higher dose reduction up to 44.89%.

The present study revealed that ATCM can reduce the $CTDI_{vol}$ by 44.89% in brain CT scan. ATCM adjusts the tube current based on body thickness during the scan [24]. Since the AP and lateral diameters of patients' heads are not the same, ATCM ensures that the tube current is tailored to the thickness of the head for each scan. Without ATCM, the tube

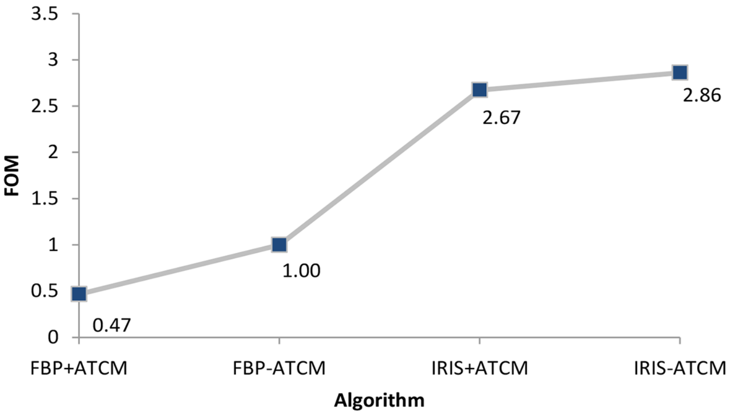

Figure 4: Figure of merit (FOM) for iterative reconstruction in image space (IRIS) and filtered back projection (FBP) algorithms with or without applying automatic tube current modulation (ATCM).

current remains constant across all projections which consequently results in excessive dose delivery in slices with lower diameter. In the present study, the mean tube current without and with ATCM was 251.73±38.15 mA and 130.91±26.55 mA respectively.

Technicians typically set the tube current based on the thickest part of the tissue, because they cannot adjust it manually according to varying thicknesses throughout the scan. When ATCM is applied, the tube current is reduced compared to what is selected by technicians, consequently decreasing the number of photons reaching both the patient and the detector. Since image noise is highly dependent on the number of photons reaching the detector, lowering the tube current results in increased image noise. In the present study, ATCM increased image noise for FBP but IRIS could compensate for the increased noise. As a result, the difference in noise levels between scans with and without ATCM was not significant for IRIS.

The subjective image scores with IRIS were consistently higher than those with FBP, regardless of ATCM. IRIS resulted in reduced noise and increased SNR as well as higher diagnostic value of reconstructed images at the same dose compared to FBP in abdominal CT (1.20±0.40 vs. 1.37±0.57; P-value<0.05) [25].

In this study, the performance of IRIS combined with ATCM was investigated in terms of dose reduction and image quality in brain CT scans for the first time. However, this study did not include additional image quality parameters, such as spatial resolution and sharpness. Additionally, the brain CT scans were performed in sequential mode. Future studies should be conducted to explore the effects of spiral scan mode on image quality taking into consideration the spatial resolution and sharpness and radiation dose in brain.

Conclusion

The IRIS algorithm can preserve the image quality when the radiation dose is significantly reduced by ATCM in brain CT scans. In contrast, the FBP algorithm combined with ATCM leads to increased image noise and decreased SNR. Although IRIS does not directly reduce the dose, image quality at lower doses is preserved for scans. Based on the findings of the present study, implementation of IRIS combined with ATCM is recommended for brain CT examinations.

Acknowledgment

We thank all those who helped us during this research.

Authors' Contribution

S. Jafari Investigation conducted the data curation, formal analysis, conceptualization, methodology, project administration, and writing – original draft, and S. Kolivand perform validation and visualization. All the authors read, modified, and approved the final version of the manuscript.

Ethical Approval

The study was approved by the research ethics committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1401.511).

Informed Consent

A written Informed consent was taken from participants before the study.

Funding

This study has been funded and supported by Vice-chancellor for Research and Technology, Hamadan University of Medical Sciences (No. 140106295603).

Conflict of Interest

None

References

1. Taweesomboonyat C, Kaewborisutsakul A, Tunthanathip T, Saeheng S, Oearsakul T. Necessity of in-hospital neurological observation for mild

traumatic brain injury patients with negative computed tomography brain scans. *J Health Sci Med Res*. 2020;**38**(4):267-74. doi: 10.31584/jhsmr.2020746.

2. Shobeirian F, Ghomi Z, Soleimani R, Mirshahi R, Sanei Taheri M. Overuse of brain CT scan for evaluating mild head trauma in adults. *Emerg Radiol.* 2021;**28**(2):251-7. doi: 10.1007/s10140-020-01846-6. PubMed PMID: 32844320.
3. Jafari S, Tavakoli MB, Zarrabi A. Lomustine Loaded Superparamagnetic Iron Oxide Nanoparticles Conjugated with Folic Acid for Treatment of Glioblastoma Multiforma (GBM). *Iran J Pharm Res*. 2020;**19**(2):134-44. doi: 10.22037/IJPR.2020.1101032. PubMed PMID: 33224218. PubMed PMCID: PMC7667540.
4. Novoa Ferro M, Santos Armentia E, Silva Priegue N, Jurado Basildo C, Sepúlveda Villegas CA, Del Campo Estepar S. Brain CT requests from emergency department: reality. *Radiologia (Engl Ed).* 2022;**64**(5):422-32. doi: 10.1016/j.rx.2020.08.005. PubMed PMID: 33131785.
5. Rostampour N, Jafari S, Saeb M, Keshtkar M, Shokrani P, Almasi T. Assessment of skyshine photon dose rates from 9 and 18 MV medical linear accelerators. *International Journal of Radiation Research*. 2018;**16**(4):499-503. doi: 10.18869/acadpub.ijrr.16.4.499.
6. Bos D, Guberina N, Zensen S, Opitz M, Forsting M, Wetter A. Radiation Exposure in Computed Tomography. *Dtsch Arztebl Int.* 2023;**120**(9):135-41. doi: 10.3238/arztebl.m2022.0395. PubMed PMID: 36633449. PubMed PMCID: PMC10198168.
7. Cheki M, Jafari S, Najafi M, Mahmoudzadeh A. Glucosamine Protects Rat Bone Marrow Cells Against Cisplatin-induced Genotoxicity and Cytotoxicity. *Anticancer Agents Med Chem.* 2019;**19**(14):1695-702. doi: 10.2174/1871520619666190704164126 . PubMed PMID: 31272360.
8. Jaffe TA, Hoang JK, Yoshizumi TT, Toncheva G, Lowry C, Ravin C. Radiation dose for routine clinical adult brain CT: Variability on different scanners at one institution. *AJR Am J Roentgenol.* 2010;**195**(2):433-8. doi: 10.2214/AJR.09.3957. PubMed PMID: 20651201.
9. Semghouli S, Amaoui B, El Kharras A, Bouykhlaf K, Hakam OK, Choukri A. Evaluation of radiation risks during CT brain procedures for adults. *Sci Perspect.* 2019;**12**:100407. doi: 10.1016/j.pisc.2019.100407.
10. Jafari S, Karimi M, Khosravi H, Goodarzi R, Pourkaveh M. Establishment of Diagnostic Reference Levels for Computed Tomography Scanning in Hamadan. *J Biomed Phys Eng.* 2020;**10**(6):792-800. doi: 10.31661/jbpe.v0i0.2004-1099. PubMed PMID: 33364217. PubMed PMCID: PMC7753261.
11. Joyce S, O'Connor OJ, Maher MM, McEntee MF. Strategies for dose reduction with specific clinical indications during computed tomography. *Radiography (Lond).* 2020;**26**(suppl 2):S62-8. doi: 10.1016/j.radi.2020.06.012. PubMed PMID: 32682731.
12. Nagayama Y, Iwashita K, Maruyama N, Uetani H, Goto M, Sakabe D, et al. Deep learning-based reconstruction can improve the image quality of low radiation dose head CT. *Eur Radiol.* 2023;**33**(5):3253-65. doi: 10.1007/s00330-023-09559-3. PubMed PMID: 36973431.
13. Fusco R, Setola SV, Raiano N, Granata V, Cerciello V, Pecori B, Petrillo A. Analysis of a monocentric computed tomography dosimetric database using a radiation dose index monitoring software: dose levels and alerts before and after the implementation of the adaptive statistical iterative reconstruction on CT images. *Radiol Med.* 2022;**127**(7):733-42. doi: 10.1007/s11547-022-01481-w. PubMed PMID: 35579854.
14. Schofield R, King L, Tayal U, Castellano I, Stirrup J, Pontana F, et al. Image reconstruction: Part 1 - understanding filtered back projection, noise and image acquisition. *J Cardiovasc Comput Tomogr.* 2020;**14**(3):219-25. doi: 10.1016/j.jcct.2019.04.008. PubMed PMID: 31023632.
15. Kataria B, Nilsson Althén J, Smedby Ö, Persson A, Sökjer H, Sandborg M. Image quality and potential dose reduction using advanced modeled iterative reconstruction (ADMIRE) in abdominal CT-A review. *Radiat Prot Dosimetry.* 2021;**195**(3-4):177-87. doi: 10.1093/rpd/ncab020. PubMed PMID: 33778892. PubMed PMCID: PMC8507455.
16. Wei X, Cui L, Li Z, Yi W, Chen X, Ying J. Application of CT Image Scanning Technology Based on Iris Algorithm in Clinical Diagnosis of Patients with Hepatobiliary Stones. *Journal of Medical Imaging and Health Informatics.* 2021;**11**(1):203-8. doi: 10.1166/jmihi.2021.3438.
17. Ghetti C, Ortenzia O, Serreli G. CT iterative reconstruction in image space: a phantom study. *Phys Med.* 2012;**28**(2):161-5. doi: 10.1016/j.ejmp.2011.03.003. PubMed PMID: 21497530.
18. Hur S, Lee JM, Kim SJ, Park JH, Han JK, Choi BI. 80-kVp CT using Iterative Reconstruction in Image Space algorithm for the detection of hypervascular hepatocellular carcinoma: phantom and initial clinical experience. *Korean J Radiol.* 2012;**13**(2):152-64. doi: 10.3348/kjr.2012.13.2.152. PubMed

PMID: 22438682. PubMed PMCID: PMC3303898.

19. Söderberg M. Overview, practical tips and potential pitfalls of using automatic exposure control in CT: Siemens CARE Dose 4D. *Radiat Prot Dosimetry.* 2016;**169**(1-4):84-91. doi: 10.1093/rpd/ncv459. PubMed PMID: 26567324.
20. Duan X, Ananthakrishnan L, Guild JB, Xi Y, Rajiah P. Radiation doses and image quality of abdominal CT scans at different patient sizes using spectral detector CT scanner: a phantom and clinical study. *Abdom Radiol (NY).* 2020;**45**(10):3361-8. doi: 10.1007/s00261-019-02247-1. PubMed PMID: 31587100.
21. Harun HH, Karim MKA, Abbas Z, Sabarudin A, Muniandy SC, Ibahim MJ. Effect of iterative reconstruction algorithm levels on noise index and figure-of-merit in CT pulmonary angiography examinations. *J Xray Sci Technol.* 2020;**28**(5):893-903. doi: 10.3233/XST-200699. PubMed PMID: 32741801.
22. Bruder H, Sunnegardh J, Stiersturter K. Translation of statistical iterative reconstruction into nonlinear image processing. In Proceedings of the Annual Meeting of the Radiological Society of North America; Chicago: RSNA; 2010.
23. Korn A, Fenchel M, Bender B, Danz S, Hauser TK, Ketelsen D, et al. Iterative reconstruction in head CT: image quality of routine and low-dose protocols in comparison with standard filtered back-projection. *AJNR Am J Neuroradiol.* 2012;**33**(2):218-24. doi: 10.3174/ajnr.A2749. PubMed PMID: 22033719. PubMed PMCID: PMC7964820.
24. Jiang D, Wang Y, Zhang P, Liu Z. Comparison of image quality and radiation dose of different scanning methods used for computed tomography of the unilateral shoulder. *Acta Radiol.* 2023;**64**(5):1919-26. doi: 10.1177/02841851231153031. PubMed PMID: 36775984.
25. Wang R, Yu W, Wu R, Yang H, Lu D, Liu J, et al. Improved image quality in dual-energy abdominal CT: comparison of iterative reconstruction in image space and filtered back projection reconstruction. *AJR Am J Roentgenol.* 2012;**199**(2):402-6. doi: 10.2214/AJR.11.7159. PubMed PMID: 22826403.