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ANALYSIS OF RADIATION DOSE REDUCTION AND NOISE AT DIFFERENT CT ACQUISITION PROTOCOL USING HEAD PHANTOM ON MDCT SCANNER

Medical Physics

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ABSTRACT

Introduction: Since the 1970s, CT scans have become widely used but contribute significantly to patient radiation doses. Head CTs, particularly in young adults, require dose optimization. Techniques like reducing kVp/mAs and optimizing protocols can minimize radiation exposure. This study aims to identify reduced-dose head CT protocols that preserve image quality.**Methods:** This cross-sectional phantom study in a radiology department collected console data over two months, with ethics approval. Based on expected variance and Epitools software, at least five readings per protocol were taken. **Results:** CTDIvol. decreased steadily with reduced mAs and kVp in head CT protocols, while noise increased. Four protocols—120 kVp/200 mAs, 120 kVp/150 mAs, 100 kVp/230 mAs, and 100 kVp/200 mAs—provided significant dose reduction (up to 49.5%) with noise ≤1.5%, meeting IAEA diagnostic quality standards and representing optimal lower-dose alternatives to routine protocols.**Conclusion:** This study demonstrated that significant radiation dose reductions in adult head CT scans are achievable by adjusting kVp and mAs, even when using filtered back projection (FBP) reconstruction. Four optimized protocols with noise ≤1.5% balanced reduced CTDIvol. and preserved diagnostic image quality. These protocols can improve patient safety and operational efficiency, but require further clinical validation.Implications for practice: Implementing these protocols enhances patient safety, preserves diagnostic quality, prolongs equipment life, and supports cost-effective radiology practice pending clinical validation. Clinical validation is needed before routine implementation, but the study provides a framework for departments using filtered back projection to optimize protocols and balance patient safety with imaging needs.

KEYWORDS

Computed Tomography (CT), Computed Tomography Dose Index (CTDI), Ctdi Vol., Noise, Image Quality

INTRODUCTION

Since its initial use in clinical settings in the early 1970s, computed tomography (CT) has developed into a highly sophisticated technology capable of producing high-quality body cross-sectional images from X-rays[1] .According to recent estimates, computed tomography (CT) scans account for 60–70% of patient doses in certain large medical centers, representing an ever-increasing share of radiological radiation.[2] This has increased the sense of urgency surrounding the need for dosage reduction techniques. Every year, more than 300 million CT scans are conducted worldwide.[3] This figure has risen by around 10% every year. *CT head is performed most frequently for trauma evaluation, strokes, hemorrhages, initial screening and neurological functions. Most commonly CT head perform in young adults 20 to 40 years age group which are more prone to accidents, sports related injuries, meningitis, or some congenital brain anomalies.* [4], [5], [6]*Most of the work in literature on the radiation dose in abdomen and chest CT, head CT radiation is less explored as compared to other.* Numerous studies demonstrate that lenses are among the human body's most radiosensitive structures, making cautious radiation dose management techniques necessary during cranial computed tomography exams. [7], [8]

Many CT dose-saving techniques have been developed in response to growing concerns about possible radiation risks from CT scans. By implementing strategies such as appropriate justification, protocol optimization, the use of AEC and iterative reconstruction, reduction of the scan range of CT exams, limiting/omitting pre-contrast scanning in multi-phase CT procedures, and limiting repeat scans the dose can be minimized. These tactics can be applied to optimize CT imaging procedures and increase the benefit-risk ratio of CT exams. Understanding CT dose parameters, such as tube potential, tube current, pitch, weighted CT dose index (CTDIw), volume CT dose index (CTDIvol.), dose length product (DLP), and effective dose, is necessary for dosage optimization. [9], [10], [11] Among these various techniques, one of which is reducing kVp & mAs, particularly by reducing the mAs image noise will increase which will compromise diagnostic image quality. [12] Efforts are required so that a balance is reached between diagnostic accuracy and patient safety while optimizing patient dose. [4], [13], [14]

Finding reduced dose head CT protocols (with lowered kV & mAs) that maintain optimal image quality is the goal of this phantom-based study.

MATERIALS AND METHODS

This Cross-sectional Comparative study was conducted in Department of Radio diagnosis of GTB Hospital (tertiary care teaching hospital) over two months' period. The required data was collected after approval from the Institutional Ethics Committee- Human Research. Waiver for written informed consent was taken as only data from the console was be recorded it was phantom based study and there was no patient interaction.

From the study by Santos et al it is expected that the standard deviation at any given CT acquisition protocol is expected to be 0.11 with a confidence level of 95% & acceptable error as 0.1. The sample size required to estimate the mean CTDIvol. Is calculated to be 5 using Epitools Software. Thus, a minimum of 5 readings were taken for each of the CT acquisition protocol protocols.

The data collected was converted into a computer-based spreadsheet. The values of air kerma, CTDIw, CTDIvol. and noise they were calculated and expressed as mean ± standard deviation (SD).

EQUIPMENTS

1. The CT scanner used for the study was a 64 slice MDCT scanner SOMATOM DEFINITION AS by SIEMENS HEALTHINEERS.

2. The phantom used in the study was a standard adult head phantom constructed of polymethylmethacrylate (PMMA). The typical adult head phantom is cylindrical structure, measuring 15 cm in length and 16 cm in diameter. In head CT scans, this phantom is regarded as the standard of excellence for the dose reference. The five apertures on this cylindrical phantom four at the periphery and one in the center—are 90 degrees apart and are used to orient the dosimeters. The holes are 15 cm long and 1.25 cm in diameter. One centimeter separates the phantom's edge from the center of the peripheral apertures.

3. A Pencil Ionization Chamber was used to measure the CT air kerma in PMMA (Ck, PMMA,100) in each opening of phantom.

4. CNMC Model T10010 UNIDOS* E Field Class Dosimeter which is connected with pencil ionization chamber to display readings.

TECHNIQUE OF DATA ACQUISITION

The CT machine was set in patient mode. The head phantom, which had PMMA rods in all of its apertures, was placed at the isocenter of the gantry with help of the CT scanner lasers. The openings were aligned at the 3, 6, 9, and 12 positions of an analog clock. A scout carried out to verify the proper alignment of the phantoms with all PMMA rods placed. Thereafter one PMMA rod at 3 'o' clock was removed and pencil ionization chamber positioned in the slot. The other slot was filled with PMMA rods and exposure was made.

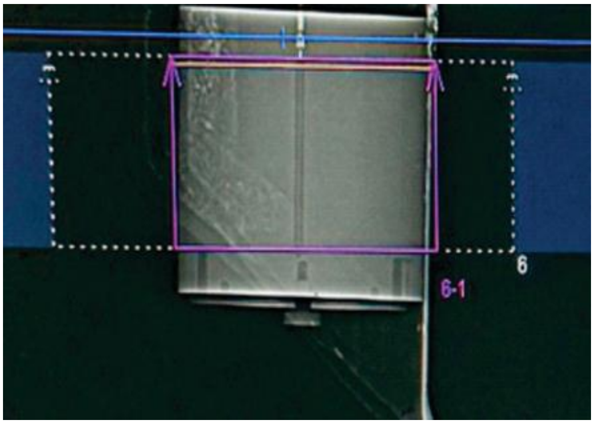

Figure 1:Scout image of Head phantom

The remaining rods were then removed one at a time so that the pencil ionization chamber could be set and the dosage measurements could be targeted in the five positions. The remaining holes for each chamber placement were filled with PMMA rods. Next, in addition to the standard CT procedure, we used eight different protocols to obtain a 10 cm scan of the central region of the head phantom in helical mode.[15] The image reconstruction (1.25mm), beam thickness, tube time, and pitch (1.2) were all identical to those of the standard technique.

Table 1. Depicting the routine and 8 different protocols used in the study

Protocol	kV	mAs
Routine	**120**	**230**
1.	120	200
2.	120	150
3.	120	100
4.	120	70
5.	100	230
6.	100	200
7.	100	150
8.	100	100

Using a UNIDOSE dosimeter that was connected to a pencil ionization chamber, five CTDI100 readings were obtained for each of the eight protocols, four at the ionization chamber's periphery (i.e., 3, 6, 9, 12, "o" clock position) and one in the center. For every protocol, we thus acquired five CTDI100 values. Weighted and volumetric CT Dose Index values (CTDIw, CTDIvol) were computed from these average values.

Calculation of dose indexes

For every position inside the phantom, one measurement of air kerma (mGy) was made. The Computed Tomography Dose Index in air, which is commonly used in dosimetric evaluations, could be computed as a result to the data. These indices can be used to measure the total radiation in a 100 mm length, which is the same length as the ionization chamber, as defined by equation (1).

$$\mathbf{CTDI_{100}} = \frac{1}{nT}\int_{-50}^{+50} \mathbf{D(Z)dz} \qquad (1)$$

Where, **n:** number of slices, **T:** is the slice thickness, **D (z):** measurements of air kerma (mGy) were taken per position inside the phantom.

After obtaining the different CTDI on the five locations within the phantoms, equation (2) is used to calculate the Weighted Computed Tomography Dose Index.

$$\mathbf{CTDIw} = \frac{1}{3}(\mathbf{CTDI_{100}})_{centre} + \frac{2}{3}(\mathbf{CTDI_{100}})_{periphery} \qquad (2)$$

Where $CTDI_{100}$, central and CTDI100, per stand for the dose indexes measured in each phantom's center and periphery, respectively. The dose allocated to a slice in the plane is shown by this index. The formula determines the Volumetric Computed Tomography Dose Index, which determines the average radiation dosage in the volume, due to the uniform displacement of the table in the z-axis. Because it considers the pitch information, this magnitude is commonly used as a dosage indicator for a particular protocol.

$$\mathbf{CTDI_{vol} = CTDI_w} \ \mathrm{x} \ \frac{1}{Pitch} \qquad (3)$$

Calculation of Noise Percentage

For every helical CT scan, a noise analysis of the central slice image was carried out to ensure the image quality. From the central slice image of each helical scan, four regions of interest (ROI) with a diameter of 2 cm were selected. Noise (N) was then calculated using the standard deviations' percentage value in relation to the average Hounsfield Unit (HU) value. [16], [17], [18]

This is the figure depicting the technique for calculating the standard deviation.

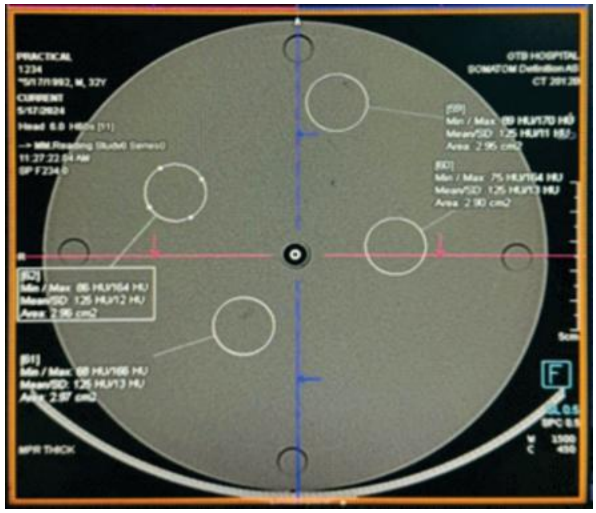

Figure 2:Noise calculation on central slice image of phantom

Using four representative ROIs from the head phantom's center slice picture, the following relationship was applied using the equation (4) for calculation of noise percentage

$$N\% = \frac{SD}{HU+1000}.100 \qquad (4)$$

Where, N%: denominated the "relative noise", **SD:** is the standard deviation measured in a 2 cm diameter ROI, **HU:** average value of the Hounsfield Units measures taken on the ROI selected.

The CTDIvol. as well as noise was compared between various protocols and protocols with noise percentage less than 1.5 % was selected to be the optimal protocol.

OBSERVATION AND RESULTS

From the values of CTDI100 at the periphery and CTDI100 at the center that were obtained from various protocols the CTDIvol. was calculated using mathematical calculation the values are depicted in table 2.

Using the routine protocol which is followed in our department at factors of 120 kVp and 230 mAs the CTDI100 value at the center was 52.61 mGy and CTDI100 at the periphery was 49.98mGy. All the other 8 protocols that we followed they had lower CTDIvol. compared to the routine protocol and lowest was seen in protocol 4 & 8 as depicted in table 2. and graph.

Table 2. Measured values of CTDIw and CTDIvol. using different protocols

Standard head phantom	Voltage (kVp)	Charge (mA.s)	CTDI 100 Periphery (mGy)	CTDI 100 Center (mGy)	CTDIw (mGy)	CTDIvol. (mGy)	CTDIvol. % Decrease
Routine	120	230	49.98	52.61	50.85	42.37	-
Protocol 1.	120	200	39.73	46.29	41.92	34.92	17.5%
Protocol 2.	120	150	32.93	38.13	34.66	28.88	31.8%
Protocol 3.	120	100	25.23	28.34	26.26	21.8	48.5%
Protocol	**120**	**70**	**19.11**	**21.92**	**20.04**	**16.7**	**60.5%**
Protocol 5.	100	230	29.41	35.74	31.51	26.2	38.1%
Protocol 6.	100	200	22.36	32.31	25.67	21.39	49.5%

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Protocol 7.	100	150	22.92	26.25	24.03	20.02	52.7%
Protocol 8.	**100**	**100**	**16.96**	**19.38**	**17.76**	**14.8**	**65%**

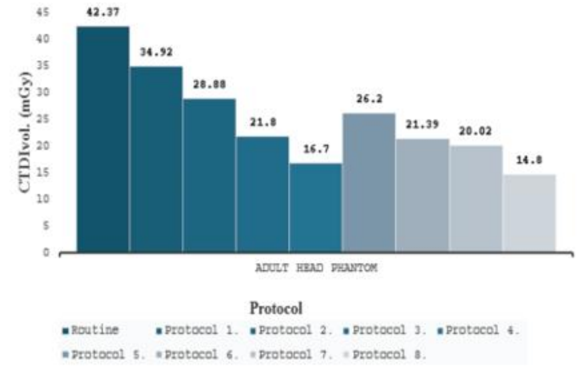

Figure 3. CTDIvol. values for standard adult head phantom obtained with routine and optimized protocol.

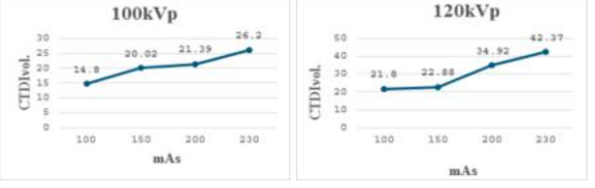

Figure 4. Effect of change in mAs at 100 & 120 kVp on CTDIvol.

As keeping the kVp constant at 120 when the mAs was decreased from 230 to 100 there was steady decrease in CTDIvol. and similar observation made at 100 kVp.

keeping other parameters constant when the mAs was 230 with higher kVp (120) the value of CTDIvol was maximum (42.37 mGy) and then decreased from 34.92 mGy to 21.8 mGy.

Fig(a) With lower kVp (100) the value of CTDIvol was decreased from 26.2 mGy to 14.8 mGy.

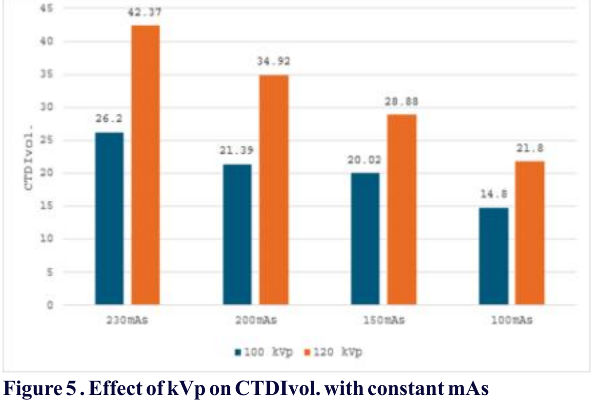

Figure 5 . Effect of kVp on CTDIvol. with constant mAs

Noise Percentage using different protocols

It was observed that the mean HU value for the central slice was same for all acquisition at 120 kVp, having 125 HU. The Standard Deviation was 11 HU for routine protocol, it was increasing from protocol 1to 4 i.e. mAs decrease the standard deviation increase suggesting more noise.

Similarly for the 100 kVp protocol the HU value was constant at 117 HU. The Standard Deviation was 16 at 100 kVp 230 mAs & it increased to 25 at 100kVp 100 mAs.

Table 3. Showing the noise percentage of routine and different protocol

Protocol	kVp	mAs	HU	Standard Deviation	Noise%
Routine	**120**	**230**	**125**	**11**	**0.9**
Protocol 1.	**120**	**200**	**125**	**12**	**1.0**
Protocol 2.	**120**	**150**	**125**	**15**	**1.3**
Protocol 3.	120	100	125	18	1.6
Protocol 4.	120	70	125	24	2.1
Protocol 5.	**100**	**230**	**117**	**16**	**1.4**
Protocol 6.	**100**	**200**	**117**	**17**	**1.5**
Protocol 7.	100	150	117	20	1.7
Protocol 8.	100	100	117	25	2.2

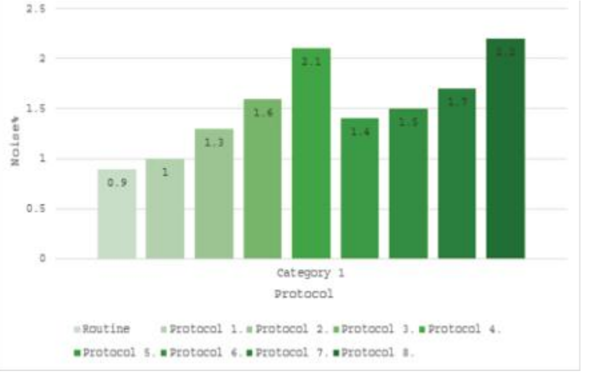

Figure6.Noise percentage at routine and different protocols

Thus, only two protocol, routine and protocol 1 (120 kVp, 200mAs) has noise level ≤ 1%. 3 protocols, protocol 2 (120 kVp, 150 mAs),5 (100 kVp, 230 mAs) ,6 (100 kVp, 200 mAs) the noise level was between 1-1.5%, rest of the protocols i.e. protocol 3,4,7,8 has noise % level is >1.5.

The optimum protocol/s were then chosen, with a noise value of less than 1.5%, which is a good substitute to be used with the goal of lowering the patient's absorbed dose while preserving the image's diagnostic quality. Thus, from our study protocol 1,2,5,6 had a noise level <1.5 % which was acceptable as alternative to routine protocol with reduced radiation dose. Among these 4 protocols when the % in CTDIvol. was seen among these protocols

The noise (calculated in %) was 0.9 % for standard dose & it increases with both decrease in mAs & kVp. The highest noise was seen at 100 kVp 100 mAs was 2.2% followed by 120 kVp 70 mAs was 2.1%

According to the IAEA study on dose reduction in CT while preserving diagnostic confidence, 1.5% is the tolerable noise level, we found that 4 protocols had acceptable noise level or image quality. These are protocol 1. (120 kVp, 200 mAs), protocol 2. (120 kVp, 150 mAs), protocol 5. (100 kVp, 230 mAs) and protocol 6. (100 kVp, 200 mAs).[19]

DISCUSSION

A CT scan's radiation dose can be affected by a number of variables, including as reconstruction methods, repeated scans, longitudinal scan duration, tube current, and tube voltage.[20] Numerous reconstruction strategies, such as the iterative reconstruction method, lower radiation doses while maintaining picture spatial resolution and minimizing noise. But the equipment we have used filter back projection reconstruction algorithm. [21], [22] Possible different lower kV & mAs can be used on a machine which have iterative reconstruction algorithm. Iterative algorithms may be able to make better use of the obtained data by generating images with higher signal to noise (SNR) at the same dose or images of similar SNR at low doses because they can model the majority of the physical parameters that filtered back projection cannot, such as the x-ray spectrum, the blurring of the focal spot, etc.[23]

The clinical use of iterative reconstruction techniques for pediatric, head and neck, abdomen, and chest CT scans is reviewed in the paper by Atul Padole et al. on CT radiation dosage and iterative reconstruction approaches. When compared to a standard chest CT examination with FBP at 7 mGy, SAFIRE has demonstrated better diagnostic confidence and lesion conspicuity at CTDIvol. of 2.5 mGy in chest CT iterative reconstruction. Likewise, CT scans of the head and neck reveal 38 mGy (200 mAs) with ASIR and 57 mGy (300 mAs) at FBP. [24], [25], [26]

Thus, it is well established that iterative reconstruction gives diagnostic image even with the lower protocols. [24], [25], [26] The equipment we used SOMATOM DEFINITION AS had FBP as the reconstruction method. It was studied how much dose reduction can be done using FBP without compromising image quality.

This work aims to offer guidance on achieving highest tolerable image noise level without subjecting patients to unnecessary risk by using an adult PMMA Head phantom followed by the comparison of the routine standard adult CT Head protocol and different combinations of variable electric current (mA) at a constant voltage (kV).

There are various Polymethylmethacrylate (PMMA) phantoms; adult body phantom, adult head and pediatric head phantom. In this study we have use (PMMA) standard adult head homogenous phantom, measuring 15 cm in length and 16 cm in diameter for standard dose assessments in computed tomography scans. The phantoms are set up with detachable inserts parallel to the axis, which allow an ionization chamber to be positioned in the middle and 1 cm from the outermost edge. It was noted that the mean HU was constant at all points at a given kVp suggesting that the phantom was homogenous. The standard CT dosimetry methodology was employed, from the measured values of CTDI100 we calculated the values of CDTIw and CTDIvol.

Table 4. Percentage decrease of CTDIvol. at different combinations and noise percentage

Protocols	Modified protocols	% of Dose reduction	Noise%
Combination 1.	120kVp/200mAs	17.5%	**1.0**
Combination 2.	120kVp/150mAs	31.8%	**1.3**
Combination 5.	100kVp/230mAs	38.1%	**1.4**
Combination 6.	100kVp/200mAs	49.5%	**1.5**

According to the IAEA study on CT dose reduction while maintaining diagnostic confidence at six different institutions, a normalization of noise measurements value of 1.5 was established for a weight of 70 kg. The image noise and normalized noise were used to determine the goal noise levels. These two target noise levels were set in order to account for the various noise levels that were deemed appropriate in the various nations. India used 15 HU for the smallest patient weight group, compared to 10 HU in Greece, Poland, Thailand, Canada, and the UK. In both cases, the increase was based on a desired noise level rise of 0.5 HU per 10 kg body weight. We have taken a similar cutoff of 1.5 and according to this, 4 combinations beside routine has a noise level of ≤1.5 as depicted in table 4. If we take 15 HU value then we get 2 combination as acceptable image noise. [19], [27]

The routine protocol (120 kV, 230 mAs) used in our department gave a CTDIvol. of 42.37. On reducing the mAs to 200 the dose reduced by 17.5 % & on further reducing mAs it reduced by almost 60% at 120 kVp 70 mAs but the noise at this combination was high at 2.1. Taking the suggested noise level (1.5) 31% reduction in dose was achieved at 120 kVp 150 mAs. Similarly, at 100 kVp, 230 mAs & 200 mAs gave the required noise level with dose reduction of 38% & 49.5%. These acquisition protocol (Combination 2, 5,6) were optimal with reduced radiation dose and noise level. But combination 6. (100 kVp, 200 mAs) give optimal dose minimization and noise compared to routine acquisition protocol.

A CT scan's noise is actually the image's inhomogeneity rather than an undesired pixel value. [4], [22] The rough look of an image in a cross-sectional image is frequently used to characterize noise. Numerous parameters, including as kVp, mAs, slice thickness, patient size, and reconstruction technique, affect this noise. [2], [28] As the mAs decrease this result of an insufficient x-ray photon flux per voxel and the amount of noise is inversely related to the amount of radiation exposed to each voxel.[9] Same was observed in our study the effect of kVp and mAs on image noise keeping other parameters constant. Keeping kVp constant at 120 when mAs was decreased from 230 to 70 image noise increased from 0.9 to 2.1 and similarly at 100 kVp when mAs was decreased from 230 to 100 image noise increased from 1.4 to 2.2. Also, when kVp was reduced from 120 to 100 at constant mAs at 230 image noise increased from 0.9 to 1.4 and similarly at 100 mAs image noise increased from 1.6 to 2.2 as depicted in table 3.

Fernanda S. Santos examined two PMMA cylindrical head phantoms at el. Each of the two head phantoms—one for a child and one for an adult—is 15 cm long. A 16-channel Philips CT scanner was used for a variety of acquisition techniques. A pencil ionization chamber was used to obtain weighted and volumetric CT Dose Index values (CTDIw, CTDIvol.) for 10 cm scans of the central region of the head phantoms in helical mode. [18], [29] For the scans, different levels of charge (mAs) and voltage (80, 100, and 120 kV) were employed.[29] It was then decided that the noise threshold in the center slice image should be 1% as a control parameter for testing novel protocols in order to guarantee the diagnostic quality of the patient's image. When testing for acceptance of CT equipment after installation, the manufacturer recommends this value. [5], [19], [21], [30], [31] According to this we get only 2 combinations as depicted in table 3. But we have taken acceptable image noise cutoff of 1.5 and according to this, 4 combinations have a noise level of ≤1.5.

Study by Fernanda S. Santos at el. also done study on optimized protocols for adult head phantom but their protocol combinations are very different from the present study.[5] This is possibly because of different machine & reconstruction algorithm used in their study. Further it is not very clearly mentioned in the study which reconstruction algorithm used.

CONCLUSION

The protocol designed are depend on equipment type & may not be applicable to other system. For the same reason we could not get studies for comparison with our results.

Limitation of this study that it is a phantom based study where the phantom is homogenous and phantom it may not be the true representation of human body so these acquisition protocols which are proposed in this study need to be validated further on the humans for the clinical application.

In order to support the adoption of optimized protocols without compromising the quality of diagnostic images, this work highlighted pertinent information on adult head CT scan dose reduction. Additionally, by using optimized protocols, the CT X-ray tube's usable life is increased, resulting in lower costs for the radiodiagnosis service. Our system was using FBP where the dose reduction increases the noise so we planned this study in order to see the lower dose protocol which could give optimal noise even with FBP.

Ethics Approvals

This research did not require Institutional Review Board approval because this study based on Phantom.

Data Availability

Raw data is not available and aggregated data is available within the manuscript

Conflicts of Interest

The authors declare that they have no competing interests.

Author contributions

All authors contributed towards data analysis. All authors read and approved the final manuscript.

Artificial Intelligent use

We have not used any AI tool or any source

Conflict of interest statement

None.

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