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Evaluation and comparison of performance of low-dose 128-slice CT scanner with different mAs values: A phantom study

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Abstract:

OBJECTIVE: Radiation dose in computed tomography (CT) has been the concern of physicists ever since the introduction of CT scan. The objective of this study was to evaluate the performance of low-dose 128-slice CT scanner with different mAs values.

MATERIALS AND METHODS: Quantitative study was carried out at different values of mAs. Philips brilliance CT phantom with Philips ingenuity 128-slice low-dose CT scanner was chosen for this study. CT number linearity, CT number accuracy, slice thickness accuracy, high-contrast resolution, and low-contrast resolution were calculated and estimated computed tomography dose index volume ($CTDI_{vol}$) for all the mAs values were recorded. Noise was calculated for all mAs values for comparison.

RESULTS: Data analysis shows that image quality was acceptable for all protocols. High-contrast resolution for all protocols was 20 line pairs per centimeter. Low-contrast resolution for 50 mAs images was 4 mm and 3 mm for other mAs protocols. Images acquired using 100 mAs revealed ring artifacts. $CTDI_{vol}$ using 50 mAs was 33% of the $CTDI_{vol}$ using 150 mAs. The dose–length product at 100 mAs was reduced to 66% of the dose–length product at 150 mAs, and the same at 50 mAs was reduced to 33%.

CONCLUSION: It is evident here that mAs has direct impact on the radiation dose to patient. With iDose4, mAs can be reduced to 50 mAs in multislice low-dose CT scan to reduce the radiation dose with minimal effect on image quality for slice thickness 4 mm. However, noise would dominate at tube current lower than 50 mAs for 120 kVp.

Keywords:

Computed tomography dose optimization, fourth-generation iterative reconstruction, image quality, low-dose computed tomography

Introduction

With an increasing number of computed tomography (CT) scans around the globe, the ratio of radiation dose received from CT among the artificial sources of radiation has elevated.[1] Several efforts have been made to reduce radiation exposure to patients while maintaining the image quality. Low-dose (120 kV_p, 30 mA) CT scanners were invented with the aim to minimize radiation dose to a patient at as low as in an X-ray.[2] This reduction in exposure increases image noise.[3-5] Efforts are being made worldwide to minimize the noise in low-dose CT.[4-6]

Fourth generation iterative reconstruction helps to reduce noise in an image and maintains spatial resolution even at low dose.[7-11] It is estimated to be perfect solution for maintaining spatial resolution even at a low dose and has reportedly

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improved spatial resolution of low-dose and ultra low-dose CT protocols when compared with filtered back projection.[8-10]

The aim of this study was to compare the scanner performance of low-dose 128-slice CT scanner equipped with fourth generation iterative reconstruction technique. The objective of this study was to evaluate and compare the performance of low-dose 128-slice CT scanner with different mAs values.

Materials and Methods

The study was carried out on Philips ingenuity 128-slice CT scanner from October to November 2020. The detector configuration of this unit was 0.5 mm × 128 and thus 64 detector rows. It has a spatial resolution of 24lp/cm. No patient was scanned for this study and the image quality assessment was based on the data analysis of phantom. Quantitative data analysis was done using CT phantom provided by Philips along with the CT scanner.

Phantom

The phantom provided by manufacturer with Philips ingenuity 128-slice CT scanner was used for this study. It has a head section with a diameter of 16 cm and body section with diameter of 32 cm [Figure 1]. The head section is made up of PVC and is filled with water and has several inserts, holes, and pins to aid for image quality evaluation.

Label 1 in Figure 1 is the head section of phantom and label 2 is body section. Label 3 is physics layer and label 4 marks the water layer for noise calibration. Label 5 shows multipin layer which is used for calibration of high-contrast and low-contrast resolution. Label 6 shows aluminum/copper wire arranged at 45° angle to measure the slice thickness. Label 7 shows the 45° wedge formed by wire on the other side of phantom as label 6.

Scanning

An anteroposterior surview was acquired with 80 kV and 30 mA. The total scan time was 2.5 s and the total scan length of surview was 250 mm, while total field of view was 32 cm. Three low-dose protocols were planned on the topogram using constant kilovoltage (120 kV_p) while changing the tube current from 150 mAs to 100 mAs and 50 mAs, covering head section of the phantom. A slice thickness of 0.7 mm was chosen. Another set of images was acquired with 80 kV and 25 mAs. Pitch used was 1 and rotation time was 1 s. Display Field Of View (FOV) was 16 cm. The technical details of phantom scan are summarized in Table 1.

Images were reconstructed in the transaxial plane and iDose4 iterative reconstruction technique was used for image reconstruction. The following parameters were checked:

1. CT number linearity
2. CT number uniformity and accuracy (image noise)
3. High-contrast resolution
4. Low-contrast resolution
5. Artifact evaluation
6. Dosimetry.

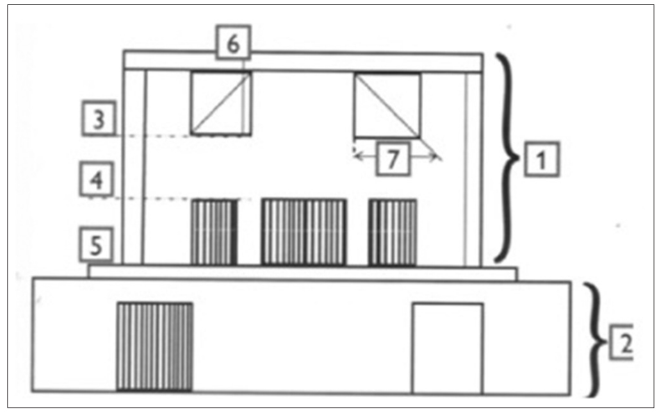

Figure 1: Schematic diagram of the Philips Brilliance Phantom used for the study

Table 1: Technical parameters used for phantom scans

mAs	Kilovltage (kV)	Slice thickness (mm)	Pitch
150	120	0.7	1
100	120	0.7	1
50	120	0.7	1
25	80	1	1

Adult head protocol was used for all the scans

Results

Data analysis

Computed tomography number linearity

CT number corresponds to the density of the medium in terms of Hounsefield Unit. The CT numbers of all the inserts/pins were noted. This procedure was done for all the mAs settings. The data of CT number linearity are tabulated in Table 2 for all three protocols.

The data show that there was no error in the CT number of water for all three mAs protocols. CT number of nylon insert (100 HU) was measured as 102 HU for 150 mAs and 50 mAs protocols and 108 HU for 100 mAs protocol. The errors however lie fairly within the tolerance limit. For polyethylene insert, the CT numbers measured were 60 HU (150 mAs), −52 HU (100 mAs), and −64 HU (50 mAs). All the measured CT number values for polyethylene lie within the tolerance limit. Teflon however showed a marked deviation from the ideal CT number. The measured CT number of Teflon insert was 911 HU for 150 mAs, 933 HU for 100 mAs, while it was 917 HU for 50 mAs value. None of these three measured CT numbers lie within the acceptable range. The measured CT numbers for acrylic insert were 141 HU (for 150 mAs), 161 HU (for 100 mAs), and 140 HU (for 50 mAs). The CT number in 50 mAs protocol shows no error, while the one in 100 mAs protocol shows the error of 21 HU. The CT number recorded for Lexan insert was 119 HU (for 150 mAs), 122 HU (for 100 mAs), and 116 HU (for 50 mAs). The CT number recorded for Lexan insert shows no error at 50 mAs and minimal error at 100 mAs and 150 mAs protocols. A graphical representation for all the three mAs values is given in Figure 2.

Effect of radiation does reduction on image quality in adult head CT with noise-suppressing reconstruction system with a 256-slice multidetector computed tomography.

High-contrast resolution/spatial resolution

High-contrast resolution is measured by visually examining the number of rows resolvable in the head section of phantom. A row is said to be resolved if the holes can be seen separated by interspace. This phantom has seven rows with the largest row of holes of 3 mm diameter and 6 mm apart, while the smallest row holes of 1 mm diameter and 2 mm apart. Images acquired using the three protocols are given in Figure 3.

Smallest row resolvable had 1.25 mm holes and 2.5 mm apart for all the three protocols. The spatial resolution of the images using 50 mAs, 100 mAs, and 150 mAs was 20 lp/cm or 2l p/mm. The spatial resolution of 20 line pairs per centimeter was sufficient to delineate the fine anatomical details in CT. Thus, CT scans with low mA values can yield optimum quality images in terms of high-contrast resolution.

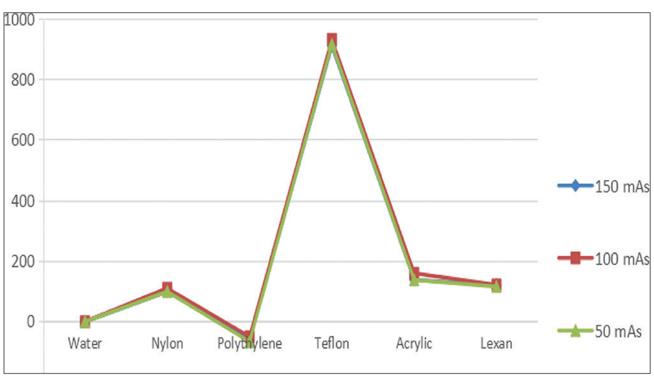

Figure 2: Computed tomography numbers recorded for all mAs values to calculate computed tomography number uniformity

Low contrast resolution

Low-contrast resolution was measured by visually observing the pins visible in the nylon insert [Figure 3].

As the two protocols using 100 mAs and 150 mAs revealed all six pins clearly, the low-contrast resolution for these was 3 mm. The protocol using 50 mAs however showed that only 5 pins were resolved. The contrast resolution using 50 mAs was 4 mm. Hence, a CT scan using 50 mAs value will compromise for low-contrast resolution.

Slice thickness accuracy

Slice thickness accuracy can be checked by measuring the distance of the rod in two consequent slices and then subtracting the distance. It was calculated for each mAs value, as given in Table 3.

The slice thickness calculated for the three protocols was the same as the chosen slice thickness. Thus, for all the three protocols, no error was observed in slice width.

Artifact evaluation

Images acquired using 50 mAs showed noise but did not reveal any artifact. Images acquired using 100 mAs had negligible noise but revealed ring artifacts. Images acquired with 150 mAs revealed noise but no artifact.

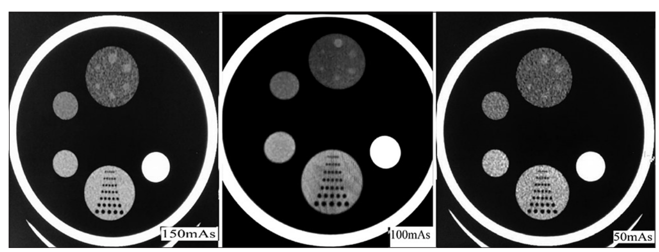

Figure 3: Images to calibrate high-contrast resolution and low-contrast resolution

Table 2: Readings for calculation of computed tomography number linearity using 150 mAs with results

Material	Ideal CT number	150mAs			100mAs			50mAs		
		CT number measured	Error (HU)	Remarks	CT number measured	Error (HU)	Remarks	CT number measured	Error (HU)	Remarks
Water	0±4	0	0	Pass	0	0	Pass	0	0	Pass
Nylon	+100±19 (+10% relative to water)	102	+2	Pass	108	+8	Pass	102	+2	Pass
Polyethylene	−75±19 (−8% relative to water)	−60	+15	Pass	−52	−23	Failed	−64	+11	Pass
Teflon	+1017±51 (+99% relative to water)	911	−106	Failed	933	−84	Failed	917	-100	Failed
Acrylic	+140±15 (+14% relative to water)	141	+1	Pass	161	+21	Pass	140	0	Pass
Lexan	+116±15 (+12% relative to water)	119	+3	Pass	122	+6	Pass	116	0	Pass

CT: Computed tomography

Dosimetry

The dose report of all three protocols is given in Table 4.

While kilovoltage was constant during all three protocols, computed tomography dose index volume ($CTDI_{vol}$) using 150 mAs was 19.4 mGy, and the $CTDI_{vol}$ using 100 mAs and 50 mAs was 12.9 mGy (−66.5% of $CTDI_{vol}$ from 150 mAs) and 6.5 mGy (−33.5% of $CTDI_{vol}$ from 150 mAs), respectively. Thus, radiation dose was reduced in proportion to the reduction in tube current. A similar reduction was observed in dose–length product. While the DLP for 150 mAs was 381 mGy. cm, the DLP for 100 mAs was 253.7 mGy. cm (−66.5% of DLP from 150 mAs) and the one for 50 mAs was 127.8 mGy. cm (−33.5% of DLP from 150 mAs). The relationship between mAs and radiation dose ($CTDI_{vol}$) is given in Figure 4.

Computed tomography number uniformity

Water section of the head phantom was chosen for the noise calibration and five circular regions of interest (ROIs) of area 200 mm^2 were selected; North, South, East, West, and Center. The CT number of all these five ROI were then recorded to calculate CT number uniformity[12] and noise.[12,13]

CT number uniformity = Mean CT number at periphery − mean CT number at the center of all five ROIs.

Difference between mean periphery CT number and mean central CT number is given in Table 5 for all values of mAs.

All the differences in mean CT number should be within + 5 HU and must lie within +7 HU.[11] The difference in mean CT numbers for all three mAs values was less than 5 HU. Thus, the mean CT number uniformity test was passed.

Table 3: Slice thickness measurements and calculations using slice thickness 0.7 mm for all mAs scans

Measurements	mAs=150	mAs=100	mAs=50
Distance of rod in Slice 1 (mm)	14.0	7.4	5.9
Distance of rod in Slice 2 (mm)	14.7	8.1	6.6
Calculated Slice thickness (mm)	0.7	0.7	0.7
Error	0	0	0
Remarks	Pass	Pass	Pass

Table 4: Computed tomography dose index and dose-length product recorded for all three mAs scans

kV	mAs	CTDIvol (mGy)	Reduction in percentage	DLP (mGy.cm)
120	150	19.4	Control	381.5
120	100	12.9	66.5	253.7
120	50	6.5	33.5	127.8

CTDIvol: Computed tomography dose index, DLP: Dose-length product

Noise was determined by the standard deviation of CT numbers in a circular ROI. Noise calculated was <15 HU for all the mAs values.

Discussion

All the calibration results showed that there was minimal effect of reducing mAs in low-dose CT scan. It was observed that CT number accuracy was up to mark except for that of Teflon. Teflon is a dense medium with CT number 1017 HU. It can be concluded that reduction of mAs will impact the density/CT number quantification of dense medium like bones and cartilages. Their density would be underestimated. The same has been observed previously by Mansour *et al*.[14] High-contrast resolution results were fairly optimum. The spatial resolution was 2 line pairs per mm in images acquired with mAs as low as 50 mAs. Hence, reducing mAs from 200 to 50 would not impact image resolution in terms of high-contrast resolution. A study by Mansour *et al*. revealed spatial resolution of 5 line pairs per mm using the American College of Radiology phantom.[14] While the low-contrast sensitivity was good for 100 mAs and 150 mAs, the same for 50 mAs was reduced. Thus, lowering mAs will impact low-contrast resolution, and therefore, low mAs values cannot be used for scans when imaging to rule out fine details smaller than 4 mm like idiopathic pulmonary fibrosis, sarcoidosis. All the images acquired using three dose protocols were free from artifacts, except for ring artifacts observed in few images with 100 mAs protocol. The radiation dose to the patient was reduced to one-third when the dose is reduced from 150 mAs to 50 mAs. While 150 mAs images have the highest noise among three mAs values, the noise was less than 15 HU in all mAs values. The images acquired with 80 kV and 25 mAs were not acceptable due to the high level of noise and photon starvation.

The result shows that optimum quality images can be acquired with low mAs using fourth-generation reconstruction technique (iDose4). However, the ultralow dose protocol cannot be implemented on this

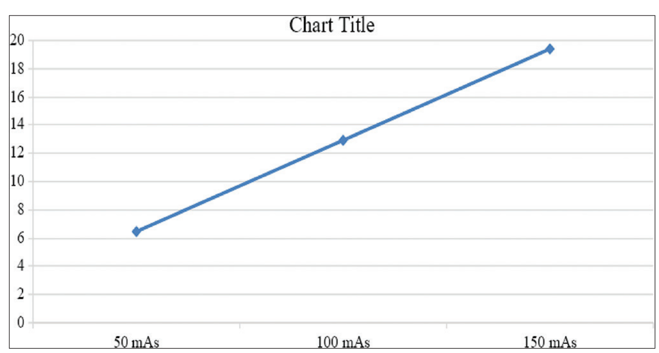

Figure 4: Graphical representation of the relationship between mAs ad computed tomography dose index volume

Table 5: Mean computed tomography numbers of regions of interest recorded and difference from mean of central regions of interest to find out computed tomography number uniformity for all mAs scans

ROI	At 150 mAs		At 100 mAs		At 50 mAs	
	Mean CT number	Difference from mean central ROI	Mean CT number	Difference from mean central ROI	Mean CT number	Difference from mean central ROIs
North	−1.9	−2.5	−0.6	−3.1	0	−3.4
South	−0.2	−4.2	1.4	−5.1	−1.2	−2.2
East	−0.3	−4.1	−1.6	−2.1	−1.0	−2.4
West	1.1	−3.3	0.7	−4.4	−0.2	−3.2
Centre	−4.4	-	−3.7	-	−3.4	-

CT: Computed tomography, ROI: Regions of interest

low-dose CT unit unless other parameters are changed such as kilovoltage, filter technique, or reconstruction technique. The lowest possible mAs required to scan the phantom to achieve optimum resolution was 50, keeping kV_p fixed at 120. CT number accuracy exceeds the tolerance limit for dense medium, but it is due possibly to the reduction of mAs from the mAs recommended at brain protocol.[15,16] It is observed that CT number uniformity test was fairly within tolerance limits at all mAs values. Ring artifact was seen in 100 mAs images which is equipment generated artifact in multislice CT scanners.[14] No artifact was observed in images acquired using 150 mAs and 50 mAs protocols. Noise was least for 100 mAs while highest for 150 mAs; however, the noise in all mAs values is insignificant. It concludes increasing mAs increases noise at 120 kV_p.[17] Other parameters including kilovoltage, filtration, slice thickness, pitch, and other reconstruction techniques were not assessed in this study.

The study compared the physical parameters of low-dose CT scanner using quality control phantom. Results revealed that radiation dose to the patient can be reduced further by reducing mAs up to 50. However, reducing mAs further or reducing kV will affect the diagnostic quality. Radiation dose does not merely depend on the mAs. Other factors such as kilovoltage, size of the patient, organs being exposed, use of adaptive collimator, contrast media, advanced features like iPatient (auto mAs adjustment), auto kilovoltage adjustment, and image reconstruction technique also affect the radiation dose.[3] However, mAs reduction can be safely utilized in combination with iterative reconstruction for all examinations except high-resolution computed tomography (HRCT) and quantitative CT. HRCT requires thin slices and is prone to error using low mAs. Quantitative CT can be erroneous for dense tissues like bone and cartilage using low mAs.

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Conflicts of interest

There are no conflicts of interest.

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