A study on the effect of low tube voltage CT cerebral angiography on radiation dose and image quality based on body mass index

Abhimanyu Pradhan [1], Rajagopal Kadavigere [2,*], Suresh Sukumar [1], Winniecia Dkhar [1]

Affiliations

[1] **Abhimanyu Pradhan,** Department of Medical Imaging Technology, Manipal College of Health Professions, Manipal Academy of Higher Education, Manipal – 576104, India. Contact – abhimanyu.pradhan@manipal.edu; ORCID ID - 0000-0002-2910-5338

[2,*] **Rajagopal Kadavigere,** Department of Radio-diagnosis & Imaging, Kasturba Medical College, Manipal Academy of Higher Education, Manipal – 576104, India. Contact – rajarad@gmail.com; ORCID ID - 0000-0003-3486-8740

[1] **Suresh Sukumar,** Department of Medical Imaging Technology, Manipal College of Health Professions, Manipal Academy of Higher Education, Manipal – 576104, India. Contact – suresh.sugumar@manipal.edu; ORCID ID - 0000-0001-9345-9790

[1] **Winniecia Dkhar,** Department of Medical Imaging Technology, Manipal College of Health Professions, Manipal Academy of Higher Education, Manipal – 576104, India. Contact – winniecia.dkhar@manipal.edu; ORCID ID - 0000-0001-5963-3230

Correspondence: Dr. Rajagopal Kadavigere (MBBS, MD**),** Department of Radio-diagnosis & Imaging, Kasturba Medical College**,** Manipal Academy of Higher Education**,** Manipal – 576104, India. Contact – rajarad@gmail.com; ORCID ID - 0000-0003-3486-8740

Abstract

Computed tomography angiography (CTA) is a non-invasive procedure to evaluate vascular anomalies. However, the high radiation dose related to the examination is a concern due to its associated cancer risk. Therefore, this study aims to investigate the effect of low tube voltage CT cerebral angiography (CTCA) on radiation dose and image quality based on body mass index. Eighty patients were included in this study, where an initial 20 patients were scanned with standard dose protocol, irrespective of BMI. The remaining 60 patients were equally allocated to BMI-based protocol, where high and obese BMI was allocated to 120 kVp protocol, normal BMI to 100 kVp protocol, and low BMI to 80 kVp protocol. Dose data and image quality data were collected after the scan. The result showed a 65% reduction in radiation dose, a 40% increase in vessel attenuation for the 80 kVp protocol, and an improved qualitative image score. In conclusion, tailoring the tube voltage with BMI can be used for CTCA while achieving significant dose re-duction without compromising image quality.

Keywords: Body mass index; CT cerebral angiography; Low tube voltage; qualitative image quality; quantitative image quality; radiation dose

Introduction

Computed tomography cerebral angiography (CTCA) is frequently performed, fast and minimally invasive examination for assessing the vasculature in cerebrovascular disease. Although, conventional angiography or the digital subtracting angiography (DSA) remains the gold standard for assessing abnormalities of cerebral vessels, but due to its procedural related complications, CTCA has slowly started to replace DSA for evaluation of cerebral blood vessels with the sensitivity of 92.5% and specificity of 98.4% (1–4). However, CTCA is associated with a high level of radiation exposure, especially to radio-sensitive organs, like the eyes and thyroid glands due to thin slice acquisition and large volume coverage (5–7). This remains a major concern for the CTCA examinations, as a considerable dose of radiation is emitted from the procedure. According to the linear non-threshold model, the risk of radiation-induced cancer is evident even in low doses of less than 100 mSv (8,9). It is therefore important to ensure that all CT examinations are justified and optimized to minimize the chance of radiation-induced cancer (10). In the event that a CTA examination is deemed medically necessary, it is crucial to apply dose optimization strategies in clinical practice (11).

Radiation dose can be optimized using a number of strategies, including reduction of tube potential and tube current, limiting volume coverage by reducing the scan length, reducing rotation time and increasing pitch, using automatic tube current modulation (ATCM)and adaptive dose shielding, and advancements in image recon-struction algorithms. (12–14). In spite of this, there have only been a few studies that have been conducted on clinical practices. Although dose reduction is clinically feasible, a number of factors need to be considered, such as image quality, noise, reproducibility, etc. Therefore, careful consideration should be given before implementing dose reduction in medical imaging. This study aims to evaluate the image quality of CT cerebral angiography performed with a body mass index (BMI) based low dose protocol.

Material and Methods

The approval for this study was acquired from Institutional Ethics Committee (IEC-545/2018), along with CTRI approval (CTRI/2019/02/017593). Patients who were referred for CT cerebral angiography (CTCA) was screened considering inclusion and exclusion criteria. The inclusion criteria included willing to participate adult patients by signing informed consent. The exclusion criteria included trauma patients. A total of 80 patients who underwent CT angiography examination were included in the study. Patient demographic data were recorded and height and weight were collected to measure body mass index (BMI). Initially, 20 patients were scanned with standard dose protocol with 120 kVp (Protocol A, SD-120) irrespective of BMI. Following that the remaining patients (20 each) were allocated to low dose protocol as per their BMI, where overweight and obese patient were allocated to low dose with 120 kVp (Protocol B, LD-120), normal weight patient to low dose protocol with 100 kVp (Protocol C, LD-100), and underweight patient to low dose protocol with 80 kVp (Protocol D, LD-80). Other scanning parameters shown in table 1 were kept constant.

Table 1. Scanning parameters for CT cerebral angiography

Protocol	**Area coverage**	**Matrix size**	**Rotation time (sec)**	**Pitch**	**Slice Thickness (mm)**	**idose**	**Collimation**	**DRI**
Standard dose protocol	Arch of aorta to vertex	512x512	0.5	0.8	0.8	3	64*0.625 mm	NA
Low dose protocol	Base of skull to vertex	512x512	0.4	0.9	0.9	4	64*0.625 mm	30

Data such as mA, mAs, scan length, CTDIvol, and DLP was collected after the scan. DLP was further used to calculate effective dose (edose) using the conversion factor suggested by Christner et al. (15). Images were reconstructed and the maximum intensity projection (MIP) images with routine batching protocol in Axial, coronal and sagittal orientation and source image with 5 mm thickness was sent to PACS. Quantitative and qualitative image analysis were performed for the acquired images.

Quantitative analysis

Quantitative analysis of the image was performed in IntelliSpace Portal (ISP) workstation by placing region of interest (ROI) in blood vessels and adjacent muscles for CT angiography phases. The ROIs were place on following blood vessels: internal carotid artery (ICA), external carotid artery (ECA), vertebral artery (VA), basilar artery (BA), anterior cerebral artery (ACA), middle cerebral artery (MCA), and posterior cer-ebral artery (PCA). Signal attenuation value for each ROI was measured in Hounsfield unit (HU). Image noise was quantified as standard deviation (SD) of each ROI of blood vessels. Signal-to-noise ratio (SNR) was calculated using the formula mean signal at-tenuation of vessel divided by SD of vessel (mean signal attenuation/SD). Con-trast-to-noise ratio (CNR) was calculated by subtracting mean signal attenuation of blood vessels with mean signal attenuation of adjacent muscles divided by vessels noise (SD of vessels) (mean signal attenuation of vessels – mean signal attenuation of adjacent muscles)/ SD of vessels).

Qualitative Analysis

Qualitative analysis was performed using the PACS viewer by two radiologists with minimum of 6 years of experience in CT angiography who were blinded from kVp and mA settings graded the image quality on quality criteria: (a) Vascular Delineation (Q1), (b) Certainty of Diagnosis (Q2), (c) Vessel contrast and overall image quality (Q3), and (d) Image artefacts (Q4) using 5 points Likert scale (table 2)

Table 2. Grading of quality criteria

Quality criteria	1	2	3	4	5
Q1	Cannot be identified	Less than 50 %	More than 50% but less than 75%	More than 75%	Entire length
Q2	Uncertainty	Marginal certainty	Adequate certainty	Good certainty	Full and confident certainty
Q3	Unacceptable	Marginally accepted	Adequate	Good	Excellent
Q4	Affecting decision making	Pronounced	Moderate	Mild	Complete absence

Statistical Analysis

Data analysis was performed using Jamovi (2.3.24). Each independent variable was initially checked for normality using Shapiro-Wilk test. Normally distributed data ($p>0.05$) are reported in mean and standard deviation (mean ± SD), whereas data which were not normally distributed ($p<0.05$) are reported in median with 25th and 75th quartile. Decision on whether to use analysis of variance (ANOVA) or Kruskal Wallis (KW) test for determining intergroup difference was decided as per ANOVA assumption. Variables meeting assumption used ANOVA (Fisher's) test with post-hoc (Tukey). Variables who failed assumption used KW test for determining intergroup difference and Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise comparison. Furthermore, for the data which was normally distributed but failed homogeneity test (Levene's test), we used ANOVA without assuming equal variance (Welch's) and post-hoc (Games-Howel) test. Intergroup difference for qualitative data was performed using KW test. Kappa statistics were performed to determine inter-rater agreement. Level of significance was set at $p<0.05$.

Results

Patient Parameters and scan parameters

Descriptive statistics for patient parameters and scanning paraments are given in table 3. The scanning parameters of cerebral angiography showed increase in the mA and mAs value when the tube voltage was reduced from 120 kVp to 80 kVp. The difference between standard dose (SD) and low dose (LD) parameters were statistically significance. The post-hoc analysis showed that the mA value was not statistically significant between low dose protocol B and C. The post-hoc result of mAs value shows no statistically significant difference between protocol A and C. Scan length were statistically significant across protocols. However, the post-hoc result shows no significant difference in scan length between protocol B and C, B and D, and C and D.

Radiation dose parameters

The radiation dose values obtained for cerebral angiography is presented in table 3. Data with normal distribution are presented in mean and SD. Non-normally distributed data are presented in median with quartiles. The result revealed that the radiation dose was reduced significantly between standard dose and low dose protocols. A total of up to 66% dose reduction in terms of CTDIvol and 78% dose reduction in terms of DLP and effective dose was achieved with low dose protocol (80kVp).

Table 3: Descriptive of patient parameters, scanning parameters and radiation dose for CT cerebral angiography

Parameters	**SD_120 (A)**	**LD_120 (B)**	**LD _100 (C)**	**LD _80 (D)**	**P value (ABCD)**	**P value (AB)**	**P value (AC)**	**P value (AD)**	**P value (BC)**	**P value (BD)**	**P value (CD)**
Age	60.3 ± 12.5	54.0 ± 12.1	60.3 ± 11.7	49.0 (25.8, 69.8)	0.178	0.427	1.000	0.444	0.358	0.956	0.404
BMI	24.1 (23.1, 25.1)	27.3 (25.9, 28.2)	21.1 ± 1.16	16.3 ± 0.9	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Scanning parameters											
mA	472 (462, 475)	485 ± 12.7	564 ± 23.3	559 (549, 590)	< 0.001	0.012	0.001	< 0.001	0.154	< 0.001	< 0.001
mAs	225 (223, 228)	207 ± 1.74	231 ± 8.55	250 ± 2.39	< 0.001	< 0.001	0.420	< 0.001	< 0.001	< 0.001	< 0.001
Scan length	363 (348, 379)	223 ± 17.6	222 ± 17.6	209 (208, 212)	<0.001	< 0.001	< 0.001	< 0.001	0.987	0.075	0.046
Dose data											
CTDI$_{vol}$ (mGy)	31.7 (31.4, 32.1)	29.2 ± 0.254	20.1 (19.6, 20.8)	10.8 ± 0.069	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
DLP (mGy*cm) ¶	1367 ± 146	841 ± 51.7	579 ± 51.0	295 ± 7.89	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Effective dose (mSv) ¶	4.24 ± 0.453	2.61 ± 0.159	1.80 ± 0.158	0.916 ± 0.025	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

¶Variables normally distributed but ANOVA assumption failed

Quantitative analysis

The mean attenuation values of cerebral vessels are represented in table 4. The result shows that the protocol D resulted in increase in the vessels attenuation up to 40% as compared to protocol A. The variance in means vessels attenuation among all the protocol were statistically significant ($p<0.001$). However, the post-hoc analysis of mean vessels attenuation values shows no significant difference between protocol A-B ($p=0.983$) and protocol A-C ($p=0.081$). When considering individual cerebral vessels selected for the analysis, the variance in the mean across all the protocol were statistically significance ($p<0.001$), except for the vessel basilar artery (BA) ($F(3,42.2)=33.6$, $p<0.001$). Post-hoc of individual vessels showed significant difference between protocol A-D, B-D, and C-D for all the vessels, protocol A-C for vessel ICA, and protocol B-C for vessels ICA and PCA. Figure 1 shows the increase in mean cerebral attenuation value while using low dose protocol.

Image noise was highest in protocol D (up to 11% increase compared to protocol A) and the variance in the mean was statistically significance ($p<0.001$). However, the post-hoc test shows that only protocol B-D and C-D difference was significant. In terms of SNR and CNR the highest value was noted in protocol D. Furthermore, the variance in the mean of SNR ($F(3,76)=7.31$, $p<0.001$) and CNR ($F(3,41.1)=27.22$ $p<0.001$) was also statistically significant. But the post-hoc result showed significant difference in SNR only between protocol A-D and B-D, and for CNR the significant difference was noted between protocol A-C, A-D, B-C, and B-D (table 4). Figure 1 shows the increase in noise, SNR and CNR value while using low dose protocol. However, the difference noted in noise and SNR were less compared to CNR when scanned with low dose protocols.

Table 4. Quantitative image quality values of cerebral vessels

Parameters	**SD_120 (A)**	**LD_120 (B)**	**LD _100 (C)**	**LD _80 (D)**	**P value (ABCD)**	**P value (AB)**	**P value (AC)**	**P value (AD)**	**P value (BC)**	**P value (BD)**	**P value (CD)**
ICA	413 (310, 449)	405 (306, 448)	458.11 ± 82.46	634.52 ± 82.99	<0.001	0.949	0.040	<0.001	0.022	<0.001	<0.001
ECA	414 (313, 442)	401 (308, 432)	435.50 ± 83.79	616.62 ± 80.33	<0.001	0.968	0.150	<0.001	0.081	<0.001	<0.001
VA	414 (313, 440)	407 (301, 438)	436.99 ± 81.53	617.73 ± 83.17	<0.001	0.981	0.104	<0.001	0.058	<0.001	<0.001
BA ‡	358 ± 74.6	352 ± 79.9	423 ± 86.3	567 ± 75.5	<0.001	0.996	0.084	<0.001	0.056	<0.001	<0.001
ACA	333.77 ± 84.39	339 (254, 412)	391.02 ± 88.82	493.02 ± 59.93	<0.001	0.999	0.178	<0.001	0.168	<0.001	<0.001
MCA	377 (290, 410)	377 (273, 411)	419.04 ± 82.14	568.96 ± 61.06	<0.001	1.000	0.086	<0.001	0.071	<0.001	<0.001
PCA ¶	289.62 ± 55.81	279.19 ± 51.23	330.67 ± 67.26	474.73 ± 32.89	<0.001	0.926	0.079	<0.001	0.016	<0.001	<0.001
Mean Vessels	378 (288, 412)	380 (283, 410)	412.74 ± 77.99	567.58 ± 59.16	<0.001	0.983	0.081	<0.001	0.046	<0.001	<0.001
Noise (Vessel SD)	4.73 (4.30, 5.36)	4.57 (4.30, 4.98)	4.44 ± 0.622	5.28 ± 0.378	<0.001	0.929	0.521	0.154	0.659	0.022	<0.001
Mean Muscle ‡	47.18 ± 4.51	46.41 ± 4.44	53.68 ± 3.15	59.60 ± 1.97	<0.001	0.959	0.001	<0.001	<0.001	<0.001	<0.001
SNR ¶	85.01 ± 19.90	72.95 ± 18.04	87.62 ± 16.73	101.22 ± 21.67	<0.001	0.202	0.973	0.045	0.082	<0.001	0.122
CNR †	61.44 ± 16.49	63.15 ± 17.29	82.72 ± 23.27	96.52 ± 11.72	<0.001	0.988	0.011	<0.001	0.023	<0.001	0.107

†ANOVA with unequal variance, ¶ANOVA analysis, ‡ ANOVA Assumption violation

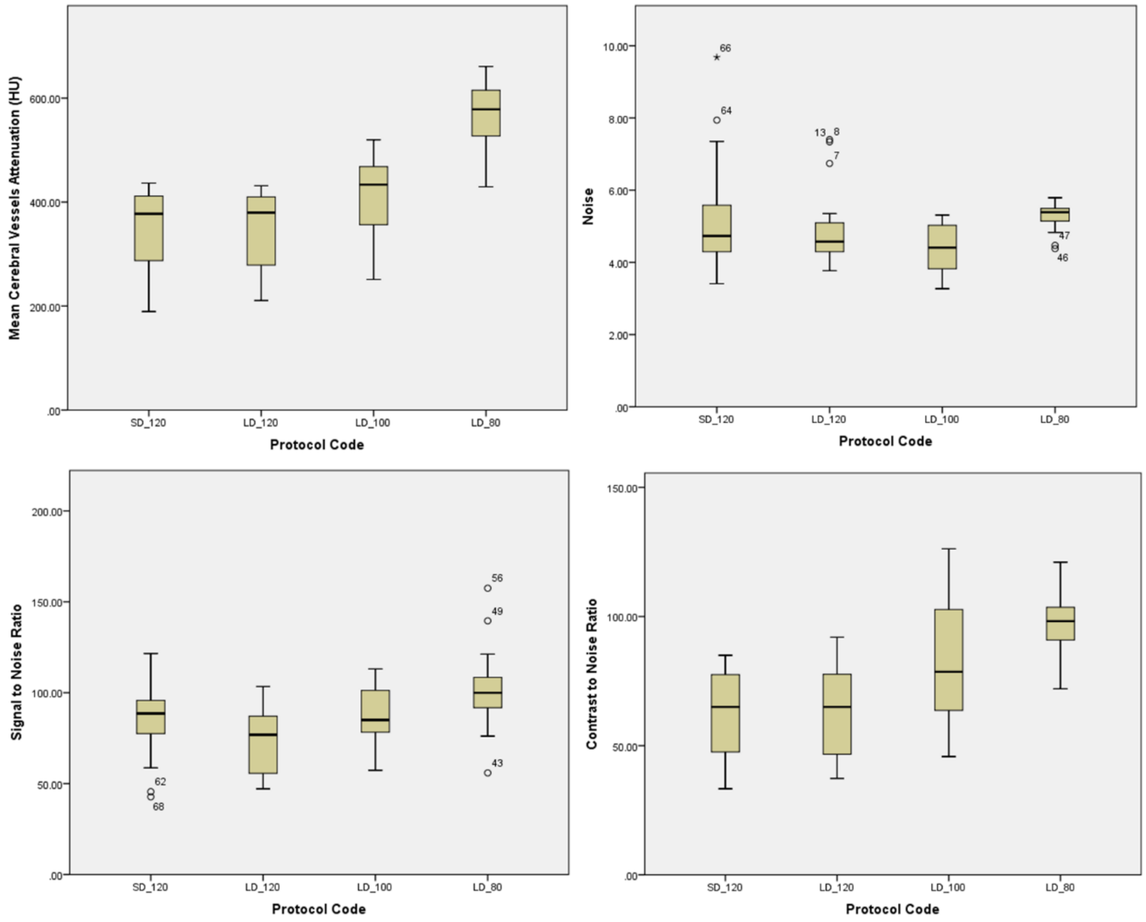

Fig. 1. Bar graph showing the quantitative image quality values for standard dose and low dose protocols.

Qualitative Analysis

Quality criteria score for cerebral vessels are represented in table 5. For all the quality criteria score was graded highest for protocol D. However, no instance of low score less than 4 was noted for quality criteria 1, 2, and 4. For quality criteria 3 the lowest score of 3 (adequate vessel contrast and overall image quality) was noted for protocol A and B with score of 3 and 2 respectively. Mean quality score (table 6) for quality criteria 1, 2, and 3 shows statistically significant difference between different protocol. However, no significant difference was noted for quality criteria 4 (image artefacts) between protocols. The inter-rater agreement shows kappa value of 0.413 ($p<0.001$), 0.388 ($p<0.001$), 0.353 ($p<0.001$) for quality criteria 1, 2, and 3 respectively. For quality criteria 4, since all the quality score were 5 for both the readers except for protocol SD-120 (table 5), the kappa value was not generated. Figure 2 shows the axial section, coronal section, and volume rendering and maximum intensity projection images scanned with four different protocol.

Table 5. Quality criteria score for CT cerebral angiography

Protocol	Quality criteria 1		Quality criteria 2		Quality criteria 3			Quality criteria 4	
	4	***5***	***4***	***5***	***3***	***4***	***5***	***4***	***5***
SD_120	11	29	4	36	3	11	26	1	39
LD_120	4	36	1	39	2	10	28	0	40
LD_100	3	37	0	40	0	11	29	0	40
LD_80	3	37	0	40	0	2	38	0	40

Table 6. Mean quality score for CT cerebral angiography

Quality criteria	SD_120	LD_120	LD_100	LD_80	p-value
1	4.72 ± 0.452	4.90 ± 0.304	4.92 ± 0.267	4.92 ± 0.267	0.021
2	4.90 ± 0.304	4.97 ± 0.158	5	5	0.032
3	4.58 ± 0.636	4.65 ± 0.580	4.72 ± 0.452	4.95 ± 0.221	0.008
4	4.97 ± 0.158	5	5	5	0.392

Fig 2. An axial, coronal, VR and MIP images of a cerebral vessels. CT images of a (A, E) 36 years old female patients scanned with protocol, (B, F) 33 years old male patients scanned with protocol B, (C, G) 50 years old female patient scanned with protocol C, and (D, H) 73 years old female patient scanned with protocol D.

Discussion

Amongst various strategies to reduce radiation dose in CT examination, lowering tube voltage is the most preferred strategy because the radiation dose is proportional to the square of tube voltage (16,17). The effectiveness of this strategy is more prominent in contrast enhanced examination, especially CT angiography examination, because of increased iodine enhancement with reduced tube voltage. This is predominantly due to the increase in photoelectric effect as the mean photon energy of low tube voltage approaches the K-edge of iodine (18–20). In the present study, we found that the contrast enhancement with low dose protocol (LD-80) increased by up to 40%. At the same time, a radiation dose reduction of more than 65% was achieved with low dose protocol (LD-80). However, this strategy of reducing the tube voltage was tailored to patient BMI, because applying low-kVp techniques uniformly for all patient sizes might not be appropriate due to high attenuation in larger patients (21).

Lowering tube voltage to reduce radiation dose to the patient has the drawback of increased noise on the image, which may impact diagnostic decision-making (22). However, this can be compensated by increasing tube current and using iterative reconstruction techniques (23,24). In the present study, we noted a significant increase in tube current with reduced tube voltage due to ATCM. Also, we used iterative reconstruction idose4TM (Philips Healthcare) for the scans. This has maintained the noise level markedly for low tube voltage techniques with only 11% increase in noise level for CT cerebral angiography. A similar trend was noted in the previous studies (16,25,26) where the noise level was higher in low dose protocol as compared with 120 kVp protocol. However, there was a difference in the percentage increase in noise level with the present study. In the study conducted by C. W. Chen et al. (16)they reported a 76% increase in noise level between tube voltage of 120 kVp and 100 kVp. Sun et al. (25) reported 105%, and P. A. Chen et al. (26) reported a 32% increase in noise level between tube voltage of 120 kVp and 80 kVp.

In CT angiography examination, vessel enhancement is a vital image quality criterion. The higher enhancement allows a broader window width to better define vessels (24). The use of low tube voltage techniques can produce better enhancement, as noted in the present study and several other studies in the literature (27–29). We noted the increase in enhancement as the tube voltage decreased from 380 HU for 120 kVp techniques to 567.58 HU for 80 kVp. Even with the high tube voltage technique, the enhancement value of the vessels was above the cut-off of 250 HU (20). A similar result (up to 45% increase in attenuation with 80kVp techniques) was observed in the study conducted by P. A. Chen et al (26). This may be due to the use of same volume and concentration of contrast material (60 ml of Omnipaque 350 mg/ml), thorough the protocols which may be the reason for similar percentage difference in vessels attenuation with the present study. In the present study, reduction of contrast volume and iodine concentration was not performed because the effect of renal toxicity was eliminated by performing a renal function test prior to CT angiography examination as per institute protocol. Hence, in the case of patients with high creatine value, the iodine concentration was changed from omnipaque 350 mg/ml to Visipaque 270 mg/ml. Thus, this condition falls in the excluded criteria of the study. Nevertheless, the reduction of iodine concentration along with contrast volume can be used for low tube voltage techniques to further eliminate the effect of contrast media on renal toxicity without compromising vessel attenuation (30,31).

The advantage of higher vessel enhancement with low tube voltage settings showed improvement in quantitative image quality matrix SNR and CNR. In the present study, the SNR and CNR values of cerebral vessels increased with low tube voltage techniques. This result showed shared opinions between the improvement and degradation of SNR and CNR of the vessels with low tube voltage techniques in the literature. E. S. Cho et al. (32)reported increased SNR and CNR values, whereas C. W. Chen et al. (16)reported lower SNR and CNR values with low tube voltage techniques. This inconsistency in findings might be due to the use of reconstruction techniques in their studies. In our study, we used iterative reconstruction idose4^{TM} (Philips healthcare), which showed improved noise reduction with low tube voltage techniques, increasing the SNR and CNR values. Regarding qualitative image quality, the mean quality score for the low tube voltage settings of 80kVp was significantly higher than other tube voltage settings in the present study. Similar results were noted with the study in the literature (32).

The use of low tube voltage settings showed a significant reduction in radiation dose in terms of CTDIvol, DLP, and effective dose. A dose reduction of up to 66% was noted in terms of CTDIvol (31.7 mGy for 120kVp standard dose to 10.8 mGy for 80kVp low dose), and 78% in terms of DLP (1367 mGy*cm for 120kVp standard dose to 295 mGy *cm for 80kVp low dose) and effective dose (4.24 mSv for 120kVp standard dose to 0.916 mSv for 80kVp low dose). Similar results were reported by other authors in the literature. However, the radiation dose value in CTDIvol, DLP, and effective dose reported by P. A. Chen et al. (26), C. W. Chen et al. (16), and E. S. Cho et al. (32) were lower than in the present study. For example, P. A. Chen et al. (26)reported a mean CTDIvol of 9.1 mGy for 120 kVp, which is lower than the dose value reported in the present study for 80 kVp. The lower radiation dose value reported in the literature may be due to the use of maximum mA in their studies. Nevertheless, the amount of radiation dose reduction for low tube voltage settings compared to standard dose was similar to the present study.

There are a few limitations in our study. Firstly, the intra-individual comparison of radiation dose and image quality was not performed due to ethical issues. Although it is the best method for proper comparison, exposing the patient multiple times for study is unethical. Secondly, in this study, no contrast volume contrast concentration and flow rate were adjusted. Although doing so, the contrast load to the patient can be reduced, especially with low tube voltage techniques. Furthermore, no vascular disease evaluation was performed in the present study. The image quality result with low tube voltage settings for all the vessels was promising, but further studies can be conducted considering the vascular disease evaluation. Lastly, we did not change the dose right index (also known as noise index) in our study. The effect of the dose right index can be explored in future studies to reduce radiation dose further so that an achievable dose can be established.

Conclusion

In conclusion, tailoring the tube voltage with the body mass index of the patient could significantly reduce the radiation dose up to 65% for low BMI patients. The enhancement of the vessels increased by 40% for 80 kVp technique with higher SNR and CNR values. Furthermore, the use of low kVp techniques improved qualitative image quality. Therefore, this strategy of tailoring BMI with tube voltage should be used for CT cerebral angiography examination.

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Ethics statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Kasturba Hospital, Manipal (IEC-545/2018). Informed consent was obtained from all subjects involved in the study.

Conflict of Interest: All the authors declare no conflict of interest.

Author Contributions

Conceptualization: Pradhan A, Sukumar S. Data curation: Pradhan A, Kadavigere R. Formal analysis: Pradhan A, Dkhar W. Investigation: Pradhan A, Dkhar W. Methodology: Pradhan A, Kadavigere R, Sukumar S, Dkhar W. Software: Pradhan A, Dkhar W. Validation: Pradhan A, Kadavigere R, Sukumar S. Visualization: Pradhan A. Writing - original draft: Pradhan A, Dkhar W. Writing - review & editing: Kadavigere R, Sukumar S.

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