Journal Interdisciplinary Health

Volume 2 Issue 1, February 2026
DOI: https://doi.org/10.61099/jih.v2i1.301

Original Article *Open Access*

Quantitative analysis of cerebral carotid CTA image quality and radiation dose at low kv and standard kv variations using bolus tracking technique

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Received: 2026-01-02 ○ Revised: 2026-01-25 ○ Received: 2026-02-02 ○ Published: 2026-02-12

ABSTRACT

Introduction: Computed Tomography Angiography (CTA) of the cerebral carotid arteries is a key non-invasive modality for evaluating vascular abnormalities. Image quality and radiation dose are strongly influenced by tube voltage (kVp). Lower tube voltage may enhance iodine attenuation and reduce radiation exposure. This study aimed to compare vascular image quality and radiation dose between low tube voltage (70 kVp) and standard tube voltage (100 kVp) in cerebral carotid CTA using bolus tracking.

Research Methodology: A quantitative comparative retrospective study was conducted on 20 patients, divided into two groups: 70 kVp (n=10) and 100 kVp (n=10). Image quality was assessed using arterial enhancement (Hounsfield Unit, HU) and Signal-to-Noise Ratio (SNR) measured at the ascending aorta, common carotid artery, and middle cerebral artery using Region of Interest (ROI) analysis. Radiation dose parameters included CTDIvol and Dose Length Product (DLP). Data normality was tested using the Shapiro–Wilk, followed by the the Mann–Whitney and independent t-test for comparative analysis.

Results: The 70 kVp protocol significantly increased arterial enhancement (e.g., ascending aorta: 697.36±81.06 HU vs 328.25±34.75 HU) and SNR (29.43±16.29 vs 15.68±7.95) compared to 100 kVp ($p < 0.05$). Radiation dose was substantially reduced, with CTDIvol decreasing from 8.08 mGy to 2.82 mGy and DLP from 284.66±10.92 mGy·cm to 102.12±3.08 mGy·cm ($p < 0.05$).

Conclusion: Low tube voltage (70 kVp) significantly improves vascular image quality while reducing radiation dose in cerebral carotid CTA. This protocol supports radiation optimization principles and can be considered an effective alternative in clinical practice.

Keywords: Angiography, Computed Tomography; Carotid Arteries; Radiation Dosage; Signal-to-Noise Ratio; X-Ray Tube Voltage.

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INTRODUCTION

Computed Tomography Angiography (CTA) of the cerebral carotid arteries plays a pivotal role in the diagnostic evaluation of cerebrovascular disorders, including stenosis, aneurysm, and arterial occlusion [1]. High-quality vascular opacification is essential to ensure accurate visualization of the arterial lumen and downstream branches, directly influencing diagnostic confidence and clinical decision-making [2]. However, optimization of CTA protocols remains a persistent challenge, particularly in balancing image quality and radiation dose. Excessive radiation exposure increases stochastic risk, while suboptimal image quality may compromise diagnostic accuracy [3]. Therefore, refining technical parameters such as tube voltage (kVp) is critical within the framework of radiation protection principles, including ALARA (As Low as Reasonably Achievable) [4], [5].

Current evidence indicates that tube voltage significantly influences both iodine attenuation and radiation dose. Lower tube voltage reduces photon energy closer to the k-edge of iodine (~33 keV), thereby enhancing photoelectric interactions and increasing vascular attenuation [5]. Several studies have demonstrated that low kVp protocols (typically 70–80 kVp) can improve vascular enhancement while simultaneously reducing radiation dose [6]. For example, Zhang et al. reported significantly higher vascular attenuation and reduced radiation exposure using low tube voltage CTA of head-and-neck vessels [7]. Similarly, Eller et al. showed that 70 kVp carotid CTA maintained diagnostic image quality with improved contrast enhancement. Zhao et al. further demonstrated that ultra-low dose CTA protocols can preserve diagnostic performance across carotid and cerebral arteries [8], [9].

Despite these advances, existing studies exhibit several limitations. First, many investigations evaluate head-and-neck CTA as a combined vascular territory, without specific focus on cerebral carotid pathways, which may present distinct hemodynamic and enhancement characteristics [10]. Second, variations in contrast injection techniques, particularly the use of bolus tracking, are often not standardized, potentially confounding enhancement outcomes [11]. Third, while most studies report general image quality, fewer provide comprehensive quantitative assessments integrating both enhancement (HU) and Signal-to-Noise Ratio (SNR) across multiple anatomical regions. Finally, evidence evaluating ultra-low tube voltage as low as 70 kVp on modern 128-slice CT systems remains limited, particularly in controlled comparative designs [12],[13].

This study addresses these gaps by conducting a focused quantitative comparison of cerebral carotid CTA using 70 kVp and 100 kVp protocols with a standardized bolus tracking technique. The novelty of this research lies in the integration of multi-regional quantitative assessment (ascending aorta, common carotid artery, and middle cerebral artery), combined with simultaneous evaluation of radiation dose parameters (CTDIvol and DLP) within a controlled acquisition protocol. Additionally, the use of a uniform scanner platform and injection protocol minimizes technical variability, enabling a more precise evaluation of tube voltage effects. Therefore, the objective of this study is to analyze the differences in vascular image quality, as measured by enhancement (HU) and Signal-to-Noise Ratio (SNR), and radiation dose parameters between low tube voltage (70 kVp) and standard tube voltage (100 kVp) in cerebral carotid CTA using the bolus tracking technique.

MATERIALS AND METHODS

Study Design

This study employed a quantitative analytic comparative design with a retrospective approach. This design was selected to evaluate differences in image quality and radiation dose between two predefined CT angiography (CTA) protocols (70 kVp vs 100 kVp) using existing clinical imaging data. The retrospective comparative framework allows controlled assessment of technical parameters without intervention bias.

Setting and Participants

The study was conducted at a radiology department equipped with a 128-slice CT scanner (SOMATOM go. Top, Siemens Healthineers). Data were collected from CTA cerebral carotid examinations performed between January and March 2026. A total of 20 patients were included using purposive sampling. Inclusion criteria were: (1) patients aged 18–60 years, (2) underwent CTA cerebral carotid examination with standardized protocol, (3) adequate diagnostic image quality, and (4) complete dose report data. Exclusion criteria included: (1) motion artifacts affecting image interpretation, (2) incomplete imaging datasets, and (3) prior vascular intervention altering anatomy. Sample size was determined based on feasibility and availability of retrospective data, with equal allocation into two groups (n=10 for 70 kVp and n=10 for 100 kVp).

Variables and Measurement

The independent variable was tube voltage (70 kVp vs 100 kVp). Dependent variables included vascular enhancement (Hounsfield Unit, HU), Signal-to-Noise Ratio (SNR), and radiation dose parameters (CTDIvol and Dose Length Product, DLP). Enhancement (HU) was defined as the mean attenuation value within the arterial lumen measured using a a Region of Interest (ROI) on axial images. SNR was calculated as the ratio between the the mean signal intensity and the the standard deviation of image noise within the same ROI. Radiation dose parameters (CTDIvol and DLP) were obtained from the CT dose report. Measurement validity was ensured through standardized ROI placement at three anatomical regions (ascending aorta, common carotid artery, and middle cerebral artery). Reliability was maintained by using consistent measurement protocols and repeated measurements by trained radiology personnel. Data sources were secondary data derived from archived CT imaging and dose reports.

Data Collection

CTA examinations were performed using a standardized protocol, including scan coverage from 2 cm below the carina to the vertex. Contrast administration utilized a dual-head injector with 50 mL iodinated contrast (300 mgI/mL) followed by 25 mL saline flush at 4.0 mL/s. Bolus tracking was applied with a threshold of 130 HU. Image reconstruction included axial images with post-processing using Maximum Intensity Projection (MIP) and Volume Rendering (VR). ROI measurements were performed on axial slices. Quality control measures included protocol standardization, calibration of CT equipment, and verification of data completeness beforenalysis.

Data Analysis

Descriptive statistics were used to summarize the mean and standard deviation of all variables. Normality was assessed using the Shapiro–Wilk test. Bivariate analysis was conducted using an an independent t-test for normally distributed data and a Mann–Whitneyey test for non-normally distributed data. Multivariate analysis was not applied due to the limited sample size and study design. Statistical analysis was performed using SPSS software (IBM Corp., Armonk, NY, USA). The level of significance was set at $\alpha = 0.05$.

Ethical Approval

This study received ethical approval from the Ethics Committee of Politeknik Sandi Karsa, Indonesia (Approval No. B-582/PT19.2.1/PP/VI/2025). Given the retrospective nature of the study, the requirement for written informed consent was waived. However, patient confidentiality was maintained by anonymizing all data beforenalysis.

RESULTS

Table 1. Characteristics of Participants

Variable	100 kVp (n=10)	70 kVp (n=10)	Total (n=20)
Age (years), mean ± SD	42.3 ± 6.8	41.7 ± 7.2	42.0 ± 6.9
Sex (Male/Female)	6/4	6/4	12/8
Clinical indication (chronic headache, suspected CVST)	10 (100%)	10 (100%)	20 (100%)

The baseline characteristics between the two groups were comparable in terms of age and sex distribution, indicating minimal demographic bias. Both groups had identical clinical indications, supporting homogeneity of the study population.

CT image results: Carotid cerebral angiography.

The following are the results of the research on carotid cerebral CTA images for standard voltage of 100 kVp and low KV at a tube voltage of 70 kVp, which shows the anatomy of the structure of the internal carotid artery to the cerebral artery.

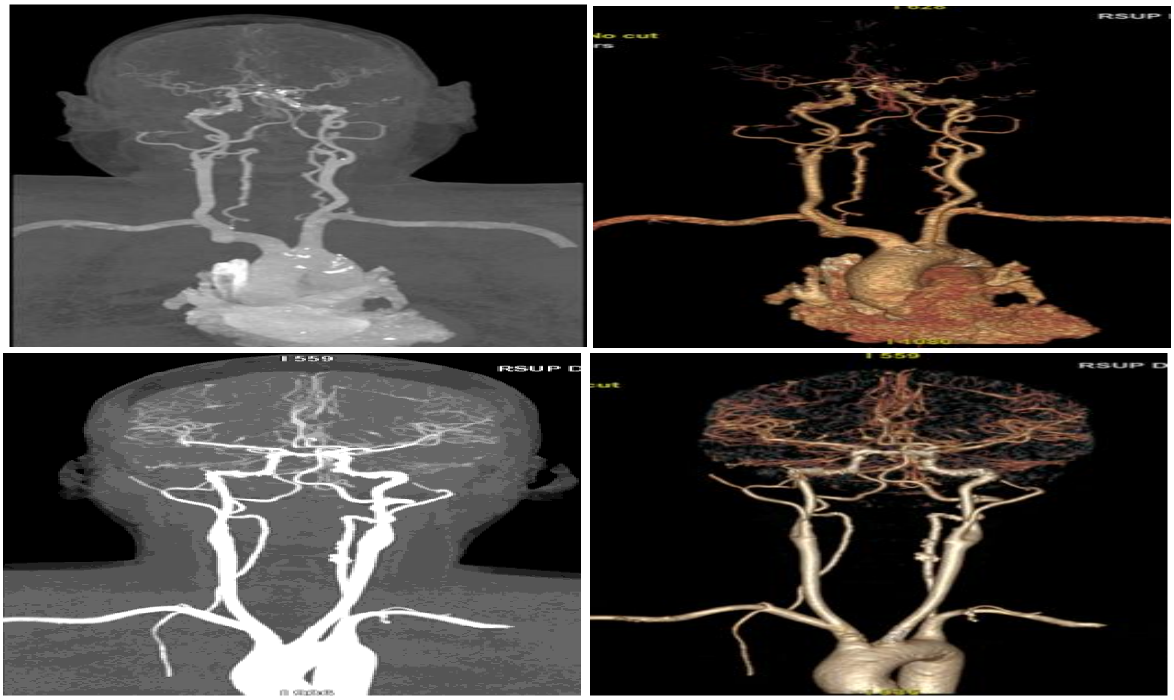

Figure 1. The results of cerebral carotid angiography CT images (top) represent images at a tube voltage of 100 kVp (standard) and (below) low kv images at a tube voltage of 70 kVp showing Maximum Intensity Projection (MIP) images and 3D VR images

Based on the results of image reconstruction using Maximum Intensity Projection (MIP) and 3D Volume Rendering (VR) techniques at a tube voltage of 100 kVp, it can be seen that the main vascular structures such as the aorta asendens, the carotid artery communis, the internal carotid artery, and the branching of the cerebri artery media can be visualized well and continuously. The contrast opacity in the lumen of the blood vessels appears homogeneous, with the boundaries of the vascular walls sufficiently clear that both intracranial and extracranial vascular anatomy can be identified diagnostically. However, quantitatively, the value of vascular enhancement at standard tube voltage tends to be at a moderate level compared to the low-voltage protocol, because the energy of X-ray photons is relatively higher, so that the photoelectric interaction with the iodine contrast medium is not optimal. This causes the intensity of iodine attenuation in the lumen of the blood vessels not to be as high as that produced at lower tube voltages.

In the results of image reconstruction using a tube voltage of 70 kVp, an increase in the opacity of contrast media in the lumen of arterial blood vessels was seen compared to the image at a voltage of 100 kVp. Vascular structures such as the aorta asendens, the carotid artery communis, the internal carotid artery, and the cerebri artery media appear more hyperdense with higher intravascular contrast to the surrounding tissues. This condition shows an increase in the value of enhancement (HU) in response to increased interaction of X-rays with iodine contrast media at an energy close to the k-edge iodine (33 keV). In addition, in MIP and VR 3D reconstructions, intracranial vascular branching appears more pronounced and detailed, particularly in the distal segment of the medial cerebri artery. This increase in vascular density contributes to improved visual quality of vascular anatomy, although theoretically, the use of low tubular tension also has the potential to increase image noise.

 E-ISSN: 3109-0281

Enhancement Value (HU) and Signal-to-Noise Ratio (SNR)

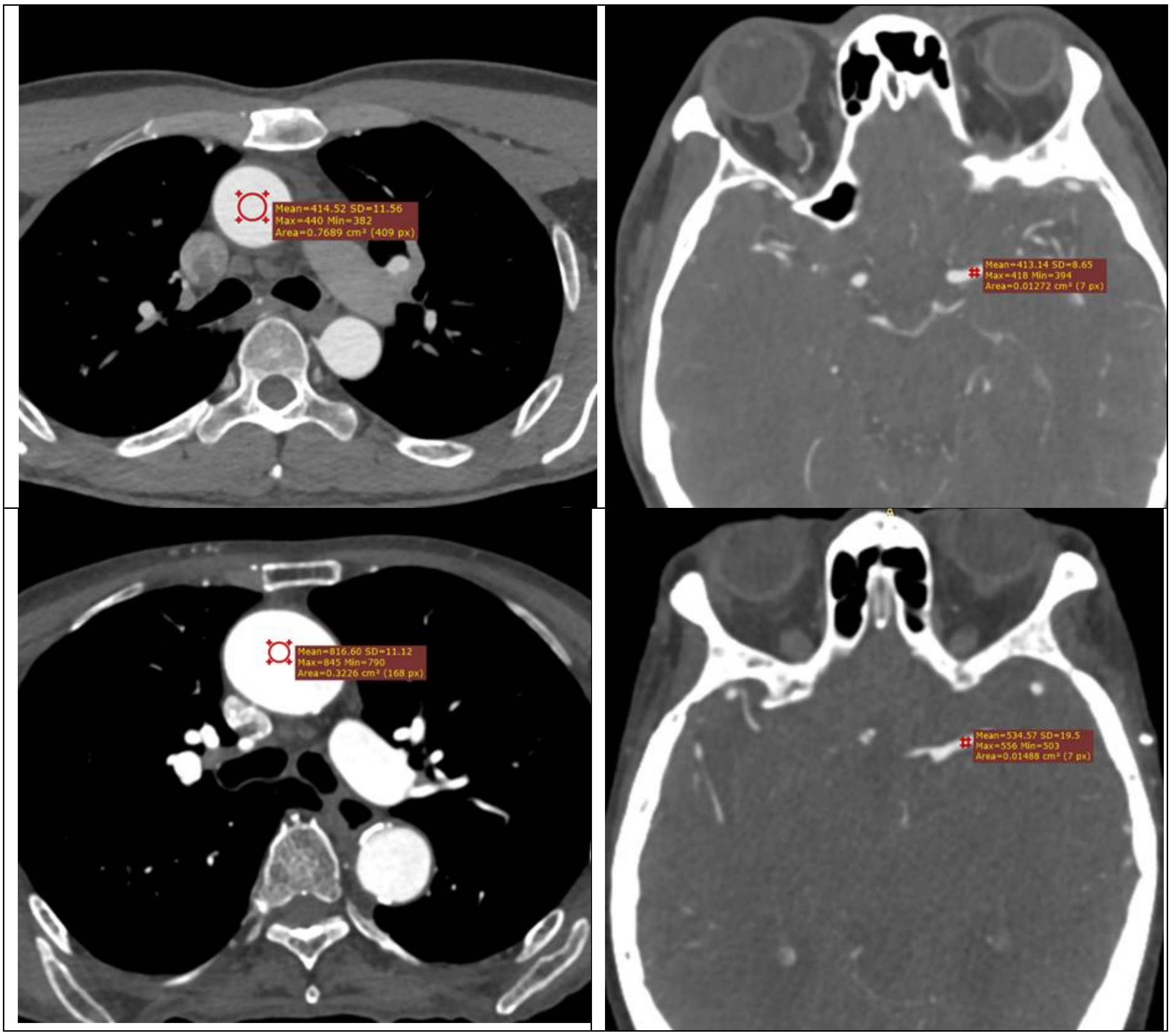

Figure 2. Comparison of the enhancement value (HU) of the arterial lumen in the axial section of theascending aorta and the medial cerebri artery on the examination of cerebral carotid TA. The upper image shows 100 kVp (standard) and the lower image is 70 kVp (low kVp), which represents a difference in the level ofopacification of the intravascular contrast medium.

Based on quantitative measurements in the standard tube voltage group (100 kVp), arterial lumen enhancement (signal) and Signal-to-Noise Ratio (SNR) were obtained at three anatomical regions: the ascending aorta (AA), common carotid artery (CCA), and middle cerebral artery (MCA), measured using Region of Interest (ROI) on axial images. The mean signal value in the ascending aorta (AA) was 328.25 ± 34.75 HU, with a noise value of 23.92 ± 7.51 and an SNR of 15.68 ± 7.95. In the common carotid artery (CCA), the mean signal was 322.74 ± 54.98 HU, with noise of 7.46 ± 1.34 and an SNR of 45.66 ± 17.32. Meanwhile, in the middle cerebral artery (MCA), the mean signal was 310.34 ± 42.88 HU, with noise of 10.71 ± 1.54 and an SNR of 29.77 ± 7.47.

Descriptively, the highest enhancement value was observed in the ascending aorta. In contrast, ntrast, the highest SNR was found in the common carotid artery, indicating relatively optimal vascular signal quality in this segment compared to other vascular regions in the 100 kVp group. In contrast, in the low tube voltage group (70 kVp), arterial lumen enhancement (signal) and SNR were also measured at the same anatomical regions (AA, CCA, and MCA) using ROI on axial images. The mean signal value in the ascending aorta (AA) was 697.36 ± 81.06 HU, with noise of 27.35 ± 8.80 and an SNR of 29.43 ± 16.29. In the common carotid artery (CCA), the mean signal was 659.99 ± 77.25 HU, with noise of 9.66 ± 2.49 and an SNR of 72.10 ± 18.93. In the middle cerebral artery (MCA), the mean signal was 608.32 ± 65.45 HU, with noise of 13.68 ± 5.54 and an SNR of 50.47 ± 16.96. Descriptively, the highest enhancement value was again observed in the ascending aorta, while the highest SNR was found in the common carotid artery. These findings indicate an overall improvement in vascular signal quality in the 70 kVp group compared to the signal distribution across vascular segments.

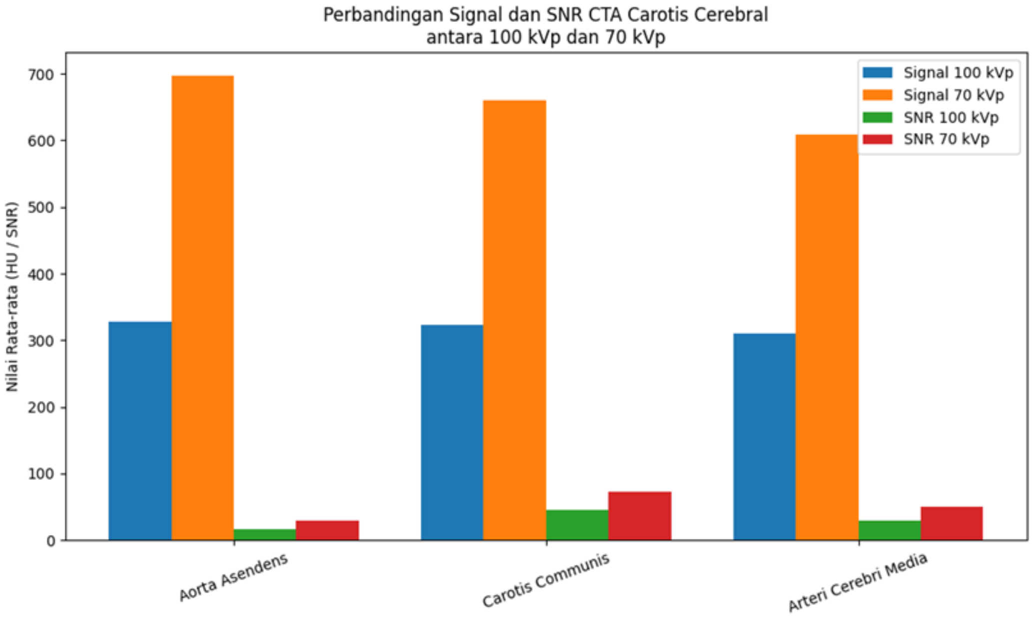

Figure 3. A comparison bar chart of the average values of the signal and SNR between 100 kVp (standard) and 70 kVp (low kVp) at three anatomical locations: the aortic asendens, the carotid communis artery, and the medial cerebri artery

Statistical analysis was conducted to compare arterial enhancement (signal) and Signal-to-Noise Ratio (SNR) between 100 kVp and 70 kVp across three anatomical regions: ascending aorta (AA), common carotid artery (CCA), and middle cerebral artery (MCA). Normality testing using the Shapiro–Wilk test indicated that most variables were not normally distributed ($p < 0.05$); therefore, nonparametric analysis using the Mann–Whitney test was applied. The Mann–Whitney test demonstrated statistically significant differences in arterial enhancement between 100 kVp and 70 kVp in all regions (AA, CCA, MCA; $p = 0.00018$), indicating higher enhancement with 70 kVp. These findings were consistent with independent t-test results ($p < 0.001$), confirming the robustness of the observed differences. Similarly, SNR analysis showed significant differences between groups across all regions (AA: $p = 0.0036$; CCA: $p = 0.0073$; MCA: $p = 0.0173$), with higher SNR values in the 70 kVp group. Parametric analysis further supported these results ($p < 0.05$). Overall, the findings indicate that low tube voltage (70 kVp) significantly improves both arterial enhancement and SNR compared to standard tube voltage (100 kVp), supporting superior vascular image quality.

Dosis radiasi

Radiation dose parameters in cerebral carotid CTA were evaluated using CTDIvol (mGy) and Dose Length Product (DLP, mGy·cm) for both standard (100 kVp) and low tube voltage (70 kVp) protocols. At 100 kVp, CTDIvol was constant at 8.08 mGy across all samples, while DLP ranged from 263.16 to 296.45 mGy·cm, with a mean of 284.66 ± 10.92 mGy·cm, indicating relatively higher radiation exposure. In contrast, at 70 kVp, CTDIvol was consistently lower at 2.82 mGy, and DLP ranged from 99.29 to 109.04 mGy·cm, with a mean of 102.12 ± 3.08 mGy·cm. These findings demonstrate a substantial reduction in radiation dose with the low kVp protocol compared to the standard protocol.

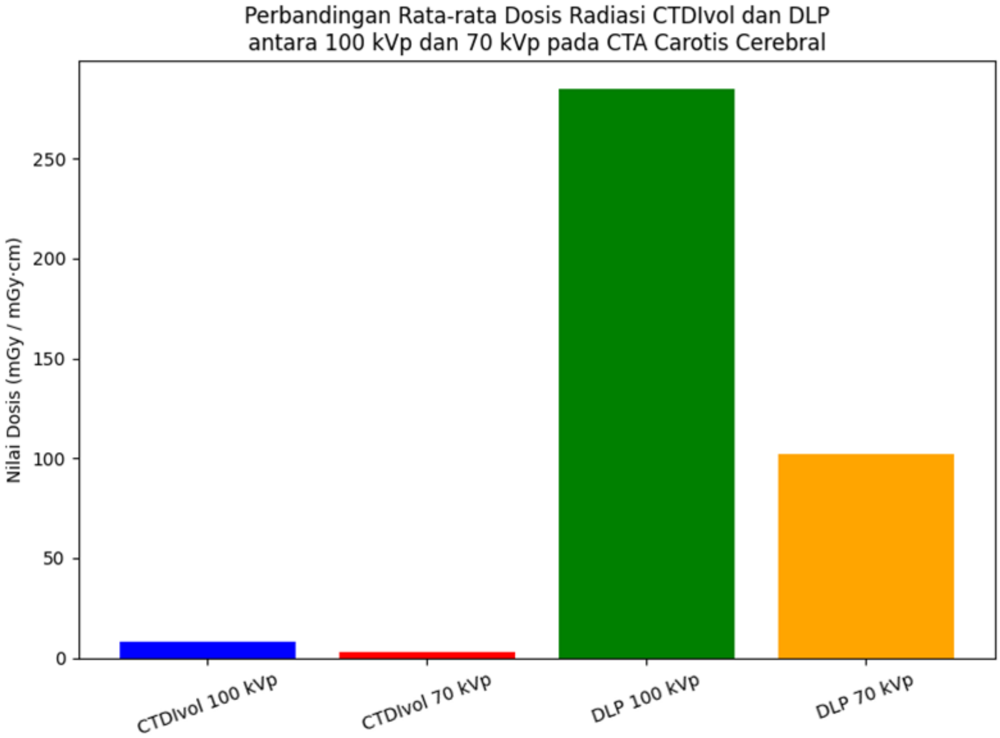

Figure 1. Bar chart illustrating patient radiation dose for standard and low tube voltage (kVp) protocols in cerebral carotid CT angiography.

Comparative statistical analysis was performed to evaluate differences in radiation dose parameters (CTDIvol and DLP) between 100 kVp and 70 kVp protocols in cerebral carotid CTA. Normality testing using the Shapiro–Wilk test showed that CTDIvol values were constant in both groups ($p = 1.000$), indicating no distribution variability and reflecting an absolute technical difference (8.08 mGy vs 2.82 mGy), corresponding to an approximate 65.1% reduction with 70 kVp. For DLP, data were normally distributed in the 100 kVp group ($p = 0.414$) but not in the 70 kVp group ($p = 0.045$); therefore, the Mann–Whitney test was applied. Results demonstrated a statistically significant difference between groups ($U = 100.00$; $p = 0.00018$). This finding was further supported by an independent t-test analysis ($t = 54.09$; $p < 0.001$). Overall, low tube voltage (70 kVp) significantly reduces radiation dose parameters (CTDIvol and DLP) compared to the standard 100 kVp protocol.

DISCUSSION

This study demonstrates that the use of low tube voltage (70 kVp) in cerebral carotid CT angiography (CTA) significantly improves vascular image quality while substantially reducing radiation dose compared to the standard 100 kVp protocol. Quantitatively, arterial enhancement (HU) and Signal-to-Noise Ratio (SNR) were consistently higher across all evaluated anatomical regions, including the ascending aorta, common carotid artery, and middle cerebral artery. Concurrently, radiation dose parameters (CTDIvol and DLP) were markedly reduced, with an approximate 65% decrease observed in CTDIvol. These findings indicate that low kVp protocols achieve a favorable balance between image quality and radiation safety.

The observed increase in vascular enhancement at lower tube voltage can be explained by X-ray attenuation physics, particularly the relationship between photon energy and the k-edge of iodine (~33 keV). At lower kVp settings, the mean photon energy approaches this k-edge, enhancing photoelectric interactions and increasing iodine attenuation within the vascular lumen. This results in higher contrast enhancement (HU). Although low kVp is typically associated with increased image noise due to reduced photon flux, the present study demonstrates that SNR is still improved, suggesting that the gain in signal intensity outweighs the increase in noise. This indicates an optimized contrast-to-noise balance, which is critical for diagnostic accuracy in CTA [14],[15].

The findings of this study are consistent with prior international research. Zhang et al. reported that low tube voltage CTA of head and neck vessels significantly increases vascular attenuation while reducing radiation dose. Similarly, Eller et al. demonstrated that 70 kVp carotid CTA maintains diagnostic image quality with enhanced contrast opacification [16]. Further confirmed that ultra-low dose CTA protocols can achieve adequate diagnostic performance across carotid and cerebral arteries [17]. Regionally, studies focusing on dose optimization in CT imaging have also highlighted the benefits of low kVp techniques in reducing radiation exposure without compromising diagnostic yield [18]. The convergence of findings with global studies can be attributed to consistent physical principles governing X-ray attenuation and iodine contrast behavior [19]. The agreement across studies reinforces the reliability of low kVp as a dose optimization strategy [20], [21]. However, some divergence in reported SNR outcomes in the literature may be related to differences in CT technology, reconstruction algorithms (e.g., iterative reconstruction), patient body habitus, and contrast injection protocols [22],[23]. In this study, the use of a standardized acquisition protocol and bolus tracking technique likely contributed to the consistent improvement in both enhancement and SNR [24], [25].

From a clinical perspective, the implementation of 70 kVp protocols in cerebral carotid CTA can enhance diagnostic confidence by improving vascular delineation while simultaneously minimizing patient radiation exposure. This aligns with the ALARA principle and supports safer imaging practices, particularly in patients requiring repeated imaging. From a systems perspective, protocol optimization using low kVp may reduce contrast media requirements and improve workflow efficiency. Furthermore, these findings contribute to the development of evidence-based imaging protocols that can be standardized across institutions, particularly in resource-limited settings where dose optimization is critical.

Strengths and Limitations

This study has several strengths, including the use of a controlled comparative design, standardized imaging protocols, and quantitative assessment across multiple anatomical regions. The integration of both image quality metrics (HU and SNR) and radiation dose parameters provides a comprehensive evaluation of protocol performance. However, several limitations should be acknowledged. The sample size was relatively small, which may limit generalizability. The retrospective design may introduce selection bias. Additionally, advanced reconstruction techniques such as iterative reconstruction were not explicitly analyzed, which could influence noise characteristics. Future studies with larger sample sizes, prospective designs, and incorporation of advanced reconstruction algorithms are recommended to validate and extend these findings.

CONCLUSIONS

This study demonstrates that the use of low tube voltage (70 kVp) in cerebral carotid CT angiography (CTA) significantly improves vascular image quality and reduces radiation dose compared to the standard 100 kVp protocol. Specifically, arterial enhancement (HU) and Signal-to-Noise Ratio (SNR) were consistently higher across all evaluated anatomical regions. At the same time, radiation dose parameters (CTDIvol and DLP) were markedly reduced, with an approximate 65% decrease in CTDIvol. These findings directly support the study objective, confirming that low kVp protocols provide superior contrast enhancement and diagnostic image quality while adhering to radiation safety principles. The results highlight that optimization of tube voltage is a critical determinant in achieving a balance between image quality and patient safety in CTA examinations. From a policy and clinical practice perspective, the adoption of 70 kVp protocols should be considered as an evidence-based strategy for dose optimization in cerebral carotid CTA, particularly in settings utilizing modern multi-slice CT systems. Implementation of standardized low kVp protocols may enhance diagnostic efficiency, reduce cumulative radiation exposure, and support broader institutional efforts toward safer and more sustainable radiological practices.

Acknowledgement

The authors would like to express their sincere gratitude to the radiology department staff for their support in data acquisition and technical assistance during the study. Appreciation is also extended to the institution for facilitating access to imaging data and supporting the research process.

Authors' contributions

Olivia Ganna conceptualized and designed the study, supervised the research process, and contributed to manuscript drafting. Akhirida Putri and Wenda Anastasia were responsible for data collection and image analysis. Suherman Hardi Saputro contributed to data analysis and interpretation. Mira Maya Kumala and Nurwahyu assisted in methodology development and manuscript revision. Purwanto contributed to the critical review and final approval of the manuscript. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this study. No financial, professional, or personal relationships have influenced the study design, data analysis, interpretation, or reporting of the results.

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